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AERONAUTICAL ENGINE LABORATORY

NAEC-AEL-1797 28 APR 1965

V/STOL PLENUM CHAMBER
COMBUSTION RESEARCH STUDY

PHASE I FINAL REPORT ON
PROBLEM ASSIGNMENT NASA DPR #R-121

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JMC

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DEFINITION OF SYMBOLS

A_H Total hole area for admission of air into the combustor liner

A_L Maximum cross-sectional area of the combustor liner

A_P Hole area for admission of air into the primary combustion zone

A_R Reference Area - Maximum cross-sectional area of the combustor outer housing

B.O. Blowout

$f/_a$ Rate of fuel flow in lb/sec divided by the rate of air flow in lb/sec

P_{T_3} Total combustor inlet pressure, in. Hg

P_{T_4} Total combustor exit pressure, in. Hg

ΔP Total pressure drop from the inlet to the exit of the combustor

S.R. Space Heat Release Rate. The rate of liberation of heat energy per unit volume of the combustor per unit atmosphere inlet pressure in BTU/HR, FT^3, ATM

T_3 Combustor inlet air temperature

T_4 Combustor exit gas temperature

ΔT Temperature rise from the inlet to the exit of the combustor

U Unstable

V_R Reference Velocity. The air velocity at the maximum outer housing cross-sectional area, measured at inlet temperature and pressure, FT/SEC.

INTRODUCTION

1. There is an increasing emphasis on aircraft operations from sites having limited or no runway capability. This trend has created a requirement for a high performance aircraft which can take off and land vertically or in a short distance. Several mechanisms for performing this function have been proposed under the general name of V/STOL (Vertical and Short Take Off and Landing) aircraft. The use of vectored thrust from a turbofan engine to provide both lift and propulsion for V/STOL aircraft presents advantages in mechanical simplicity and operational stability over multi-engine and rotating wing methods. If the engine is to be suitable for efficient operation at cruise conditions along with a capability for supersonic flight and takeoff and landing, however, it is desirable to augment the thrust without enlarging the engine. Thrust may be increased by conventional afterburning of the hot exhaust gases, but there is more to be gained, and operation is more efficient, if fuel is burned in the relatively cool fan air.

2. The objective of this program is to determine principles upon which to base the design of combustion systems which will operate efficiently in the fan duct of a turbofan engine configured for V/STOL. This objective is to be accomplished by systematic analysis of the relationship between design factors and combustion performance parameters in the anticipated range of operation of such a system. The experimental program will include the design of an experimental combustion system or systems to meet the general requirements, and tests of a sector of this system.

3. The work on this program was supported by the National Aeronautics and Space Administration under NASA DPR R-121 of 14 February 1964. This report covers the first year's work on the program.

CONCLUSIONS

4. On the basis of the analytical and experimental research conducted in the first year of the program, the following conclusions can be drawn:

a. Best use of the space available in a typical turbofan engine for vectored thrust VTOL requires the use of a combustion system within which the combustion gases are turned through an angle.

b. The most logical form of combustor to perform the above function is an annular or tubular can type.

c. The optimum cross-sectional area of a tubular can combustor for low pressure loss in this application is approximately 60% of the maximum cross-sectional area of the outer housing.

d. The optimum combustion efficiency and space heat release rate will not necessarily be reached with the same combustor size as that required for low pressure loss.

e. The presence of swirl inducers for primary combustor air is essential for good combustion, but a small penalty in pressure loss must be paid for this advantage.

f. If the proper percentage of the total air admission area is devoted to primary combustion, the total air admission area may be made large for improved pressure loss characteristics.

g. A can type combustion system can be made to operate efficiently with low pressure loss (5 - 6%) in the environment of a fan discharge plenum.

RECOMMENDATIONS

5. The recommendations for the second year of work are incorporated in the following planned project schedule:

a. Continue the investigation into the relationships between combustor design and performance in a tubular combustion chamber.

b. Establish a firm basis for evaluation of this relationship by aerodynamic studies.

c. Continue the development and study of a right angle combustor for plenum chamber burning, including the investigation of reversed flow combustion and staged fuel injection.

d. Investigate the possible advantages and disadvantages of high pressure air stabilized combustion both analytically and experimentally.

e. Combine all the information and analysis accumulated in the project into a coherent presentation of plenum chamber combustion design principles.

METHOD OF TEST AND ANALYSIS

6. The first year's work under this program consisted essentially of two phases. The first was an investigation into the requirements for plenum chamber burning, the problems involved, and possible mechanisms for performing the combustion. The second was a series of experiments with commercial and experimental combustion systems in which the relationship between combustor design and performance and that between different indices of performance were explored.

7. The plenum chamber combustion development undertaken in this program is not confined to any specific aircraft, engine, or mission. The first problem of the program, therefore, was to define the important variables within broad limits to satisfy the general requirements of V/STOL operation and supersonic flight.

8. Certain assumptions were made on the powerplant characteristics and the mission requirements for plenum chamber burning. The combustor operating variables were determined from these decisions with an allowance made for variations from the assumed conditions. The primary assumptions were as follows:

Engine: Turbofan, size undefined

a. Fan Pressure Ratio - 1.6 - 2.2

b. Fan Bypass Ratio - 1.0 - 2.0

Requirements for Plenum Chamber Burning

a. Vertical and Short Takeoff and Landing

Sea Level - Standard Day

b. Transonic acceleration to Mach 1.2 at 45,000 ft.

These requirements are modified by an upper limitation on combustor discharge temperature imposed by the presence of turning louvers in the exhaust stream, and by probable size limitations of the exhaust nozzle.

9. The variables affecting plenum chamber combustion and the range of values selected for study are shown on table 1:

TABLE 1

Combustor Inlet Pressure	20 to 90 in Hg
Combustor Inlet Temperature	140°F - 340°F
Combustor Reference Velocity	80 - 250 '/sec
Combustor Discharge Temperature	2000°F Max.

The entire range of all the variables was not necessarily covered in each test.

10. It is also desirable to set standards of performance for the combustion system. There are certain "tradeoffs" between some of the performance criteria, however, which will influence their final values in a system designed for a specific application. The function of this program is to define the relationship between these variables in a well designed system rather than to set arbitrary limits. The general application in mind however, requires that all losses be at a minimum. Therefore, the combustion efficiency must be high over a wide range of fuel flow, the space heating rate must be high to keep weight and volume at a minimum, and pressure drop must be particularly low to avoid undue losses when the combustor is not in use.

11. The overall design of a combustor for augmentation of a diverted thrust fan will differ from that of any other type of air breathing combustion system. Some characteristics which illustrate this difference can be seen in the following listing and in the schematic sketch on plate 1.

a. The inlet pressure and temperature will be low because of low fan pressure ratio compared to that of a turbojet engine main compressor.

b. There is a limited amount of space available for a large volume of air flow because of the necessity of limiting the thrust vector to a point forward of the center of gravity. Any constriction in overall powerplant diameter, especially as in pod installation, further limits volume. The effect of the limited space is to require high reference velocities and high space heat release rates (energy/per unit volume).

c. The diversion of the air flow through two changes in direction causes asymmetry in the velocity profile which makes a uniform temperature distribution difficult to achieve.

d. There is a wide range of fuel flow required. The delicate control required for VTOL and hover and the changes in lift required with changing load create a need for thrust variation over a wide range. For economy, operation should be efficient over the entire range.

e. The pressure drop must be very low. A certain degree of pressure loss must be expected for efficient combustion, but the fact that this burner may be used only during a small part of the flight makes the smallest extra loss wasteful.

f. Ignition and relight of the burner must be extremely reliable because of the critical nature of VTOL and hover.

12. Because of the limitations of space, it would appear desirable to design the combustion system to utilize as much of the available volume as possible. This requirement can be modified, however, where the extra problems in maximum volume utilization outweigh the advantages or where a specific application allows sufficient space to permit a choice. For this reason, it was decided to cover at least two extremes in this program.

13. One case to be considered is the one of maximum space utilization. As seen in plate 1, the available space consists of an annular chamber at the fan exit, followed by diversion of the flow to two essentially cylindrical ducts directed away from the engine. These are followed by the swivel nozzles. A combustion system could be designed as shown in plate 2 to initiate combustion in the annulus and continue into the exit duct. The drawbacks to this design are the high air velocity due to limited space available for diffusion from the fan exit velocity, the necessity for turning the high temperature primary combustion gases, and the complexity of the liners. There are several possible modifications to this design concept which may tend to temper these problems. Any of these which appear practical will be investigated in the experimental program.

14. The other general case to be covered is the use of a combustion system which is contained entirely in a circular cross section duct at some angle to the engine. This system will allow the use of easily fabricated and maintained liners and other components. The reference velocity will be relatively low and the hot gases will be turned only in the exhaust duct when their temperature is lowest. This type of combustion system appears to be superior, but the advantage is merely academic if a specific airframe does not have sufficient radial space. Attainment of a very high space heating rate would be favorable in this case. There are several specific configurations for a straight-through burner if a can type combustor is used. These are illustrated on plate 2. The poor diluent air penetration of the large single combustor as compared to that of the annular or multiple can type makes it appear unsuitable. The latter types are also better for testing as sectors or single cans in a small test rig.

15. Another major choice to be made is between can type structure and flameholders. The shorter length and more uniform exhaust temperature possible with the former, as well as the control of air admission to the combustion zone, are in its favor. The major drawback is the high pressure drop at high velocity. A typical flameholder, while capable of supporting efficient combustion at high velocities, also pays a penalty in pressure drop as well as in mixing distance. Another alternative is the "aerodynamic" flameholder in which the flame is supported by jets of hot high pressure air. This technique has the advantage of low pressure drop--especially when the combustor is not operating. The experimental work of the first year was confined to can type combustors, with the ultimate intent of showing the lowest pressure drops which can be achieved with good combustion at the expected reference velocity.

16. The initial effort in the experimental phase was the constructions of a tubular combustion chamber for a systematic investigation of the effects of system design on combustion performance and pressure drop in the range of operation anticipated for VTOL. A sketch of this combustor is shown on plate 3. In addition to the work on experimental combustors, tests were made of two commercial combustors with the same range of operating variables. Variations in combustor size and air admission hole size, shape, and distribution are being studied experimentally. Initial tests called for the use of one duplex fuel nozzle and one design of ignition system.

17. Combustor tests were made in two separate combustion test rigs. One is supplied by the laboratory compressed air system through a combustion heat exchanger and exhausted to the laboratory exhauster system. The other is supplied by the compressor bleed from a J57 jet engine and exhausts to the atmosphere.

18. Instrumentation at the combustor inlet plane for both rigs comprised nine total pressure probes in three rakes and three iron-constantan thermocouples in one rake, all at centers of equal areas, plus two wall static taps. At the exit plane there were three total pressure probes in one rake

and twelve thermocouples of chromel-alumel or platinum-platinum rhodium in four rakes, as well as two wall pressure taps. There were two intermediate stations of wall static pressure measurement. Air flow was measured by sharp-edged orifices and fuel flow was measured by turbine type elements and by rotameters.

19. The purpose of the series of designs tested under this program was to start with a combustor of essentially standard current design and to make incremental changes in this design. These changes illustrate a stepwise approach toward the combined pressure drop and combustion performance desired. In addition to showing progress toward an acceptable design, this part of the program should produce information useful in showing what relationships and "tradeoffs" can be expected between the important parameters at different operating conditions and in showing the progressive effect of systematic design changes on performance.

20. Plate 4 is a schematic presentation of the various combustion chambers tested under the first year's program. Table 2 lists some of the physical dimensions of the combustors. Configuration No. 1 was a tubular combustor designed to operate within the capabilities of the laboratory air system and to enable changes in configuration without complete redesign. This burner was operated with two different housings, designated as 1A and 1B, to study the effect of A_L/A_R changes. It was also operated with the diluent air admission section removed and replaced by deflectors to mix combustion gases and diluent air. This last change was a rough approximation of a more streamlined mixer to see if sufficient mixing could be obtained by this method with lower pressure drop. The initial version of burner 4, identical in air admission design to No. 1, was designed to explore further the effect of changes in A_L/A_R on burner pressure drop and combustion performance. This design was followed by a series of six changes in the primary zone swirl inducing section to optimize combustion efficiency and to study the effect of small changes in this area on air flow distribution and combustor performance. Also, from 4A, modification 5A was made to compare with burner 1XA on the basis of the change in A_L/A_R. Tests on this combustor have not been completed. Burner 4B was made to extend the curve of variation in performance of the basic burner design with A_L/A_R changes. In burner 4B1 a change in the diluent air admission area was made to learn what effect this would have on distribution of air between primary and secondary sections and its relationship with pressure drop and combustion performance.

21. Configuration RAC-1 was designed to provide maximum utilization of space in the fan discharge duct. It also incorporates a second fuel injection point which represents a reverse flow combustor. The use of two separate primary combustion zones allows investigation of fuel staging as a means of achieving a wide range of fuel/air ratios with efficient combustion. This combustor was specifically designed to operate efficiently above 200 ft/sec reference velocity.

ANALYSIS OF RESULTS AND DISCUSSION

22. Plates 5 through 25 show the results of tests on the various combustor designs. These results are presented in terms of combustor pressure drop and combustion performance. Plates 5 through 11 show the pressure drop as a function of reference velocity for the non-burning condition. Each of these plates show the performance of a series of designs which were run to show the effect of a specific design change.

23. Plate 5 gives a comparison of four combustion systems having the same air admission hole area and exit area, but with different ratios of liner to reference area (A_L/A_R). The range of pressure drop among the four designs is more than 2 to 1. The trend is toward lower pressure drop for lower values of A_L/A_R except for the lowest one, which shows an increase with this parameter. Plate 6 shows the same type of curves for four liners with a different air admission area. The results are similar.

24. A cross-plot at 150 ft/sec reference velocity of the data on plates 5 and 6 is given on plate 12. There is a minimum in the pressure drop parameter for both sets of liners at a liner to reference area ratio of approximately 0.6. The combustors with the larger air admission area appear to reach a minimum $\Delta P/P$ at a lower value of A_L/A_R. There are insufficient data points, however, to define this clearly.

25. Plate 7 is a comparison of the pressure drop characteristics for four combustors which were identical except for a progressive change in swirl slot area. Above 150 ft/sec reference velocity there is a divergence of the curves, with combustors of the highest and lowest air admission areas giving the lowest and highest pressure drop, respectively. This plate can be combined with plate 8, in which the diluent air admission area was changed to show the overall effect of hole area change.

26. The effect of change in design primary air swirl slots on pressure drop ratio is shown on plate 9. The difference between the two configurations of swirl vanes is within the error of the measurement. The burner with no swirlers has a significantly lower pressure drop. The improved combustion performance with swirlers, to be discussed later, is apparently obtained at the cost of a small increase in pressure drop.

27. Plate 10 illustrates the pressure drop characteristics of the combustors with the highest and lowest pressure loss studied in the program to date. Combustion efficiency data will show that the burner with the higher pressure drop does not necessarily have the better combustion performance. Plate 11 gives the pressure loss results for combustors J79 and RAC-1.

28. The effect of total air admission hole area on cold flow pressure loss with constant liner to reference area ratio is shown on plate 13 for three velocities. Although, as might be expected, there is a decrease in pressure loss with increasing A_H/A_R, there is evidence, as seen on plate 12, that this trend is eliminated or reversed at higher values of A_L/A_R. This effect is probably due to overwhelming influence on total pressure loss of the pressure loss in the annular air space, with high blockage design.

29. The pressure losses of the various combustors were also measured during combustion. Plate 14 shows data for a combustor with the pressure drop plotted against temperature ratio across the combustor. The curves are typical of all the combustors, and no significant differences in the trends for the various combustors were noted.

30. Plates 15 through 24 show the combustion efficiency and stability as a function of fuel to air ratio for the various combustors studied. There are curves for approximately 100 and 125 ft/sec reference velocity and for the highest velocity where data are available. The performance for the initial combustor of the experimental series is shown on plate 15, along with that for a commercial tubular gas turbine combustor. The operation with these combustors was limited to 125 ft/sec or lower. The experimental combustor was not intended to duplicate or improve upon the performance of the commercial liner but was designed as a vehicle to show the effect of changes in design. Each of these two combustors was tested with two sizes of outer housing to show the effect of variation in the ratio of liner cross section area to housing reference cross section area. The change in this parameter had a marked effect on burner pressure loss as discussed earlier, but only a small effect on combustion efficiency as can be seen on plate 15. As A_L/A_R is increased, the combustion efficiency of combustor No. 1 decreases while that of No. 3 increases slightly. This difference in response to area change may be due to the differences between the combustors in air admission hole area and in axial distribution of hole area.

31. The plots on plate 16 are for combustors which were alike in all respects except for primary swirl area. The overall design of these combustors was similar to that of No. 1A, except for a reduction in cross section area to achieve the optimum A_L/A_R ratio for low pressure loss. As the percentage of area in the primary zone is increased, in the range tested, the overall combustion efficiency appears to deteriorate, although the rich stability limit generally improves. It is apparent that there is an excess of air in the primary zone with the larger swirl slots. This effect is substantiated by the relative improvement in combustion efficiency with the largest swirl slots at high fuel/air ratios.

32. The comparison of combustors 4A5 and 4AA on plate 17 shows the effect of primary air swirlers on combustion efficiency. The two combustors shown were compared for pressure loss on plate 9. It is seen that the use of swirlers in combustor 4A5 with the same free area as the open slots in 4AA definitely improves the combustion efficiency and stability. This improvement is due to the improved mixing and longer residence time caused by the vortex created by the swirlers.

33. Also shown on plate 17 is the performance for combustors 4A and 4B1. Configuration 4B1 was made to approximate the swirler design and the percentage of area in the primary zone of No. 4A, but with an increase in the total air admission area to reduce pressure drop. The curves show the combustion performance was improved. Plates 5 and 6 show the decrease in pressure drop.

34. Burner 4B, shown on plate 18, had the large overall air admission area of 4B1, but a smaller percentage of air in the primary zone and a lower ratio of liner to reference area. The effect of this change was to lower the combustion efficiency. Apparently too little air was introduced into the primary because of the smaller primary holes and the lower resistance to air flow toward the downstream holes. The percentage of air entry holes in the primary was then increased to that of 4B1 in combustor 4B2 (plate 18) by decreasing the diluent area. The combustion performance improved, as was expected.

35. The performance of remaining burners is shown on plate 18. The J79 represents a modern high performance jet engine combustor operated in the range of fan air burning, for comparison with the experimental combustors. Combustor RAC-1 is the first model of a combustor specifically designed to operate under the conditions expected in a fan plenum of an engine configured for VTOL. This initial design shows the expected improvement at high reference velocities.

36. The combustion efficiency of the various burners was plotted against reference velocity using the values obtained at a fuel/air ratio of 0.015. This relatively low fuel/air ratio was selected so that all the combustors could be compared on the same basis. The plots (plates 19 through 22) show that there is a sharp drop-off in efficiency above 125 ft/sec for all the burners except RAC-1. This result was expected as they were volume limited for operation at higher velocities, as well as possibly incorporating design features unsuitable for such operation. The experimental combustors were made small so that they would be sensitive to small changes in design at the higher velocities and would enable a determination of the limiting practical size. The relationships of the burners at 100 and 125 ft/sec were previously discussed. Additional information to be gained from these curves is the effect of pressure, and the variations in performance at other velocities. In general the effect of pressure difference between 60 and 90 inches of mercury was small, especially at lower velocities, where there were no appreciable differences. The data at reference velocities up to 200 ft/sec show the same trend between burner designs seen at 125 ft/sec. Combustor No. RAC-1 has significantly better performance than the others at the higher velocities, as indicated earlier.

37. Some of the information gained from the plots of combustion performance previously discussed has been summarized on plates 23 and 24. Plate 23 shows the effect of primary hole area on combustion efficiency with other parameters held constant. The optimum value for this series appears to be 15% or less of the total hole area in the primary zone. The decrease in performance with larger amounts is more severe at high velocities. There is a need to extend this curve to lower values of primary area to complete the analyses. In addition, the relationship should be checked with other swirler designs and other ratios of total hole area to reference area.

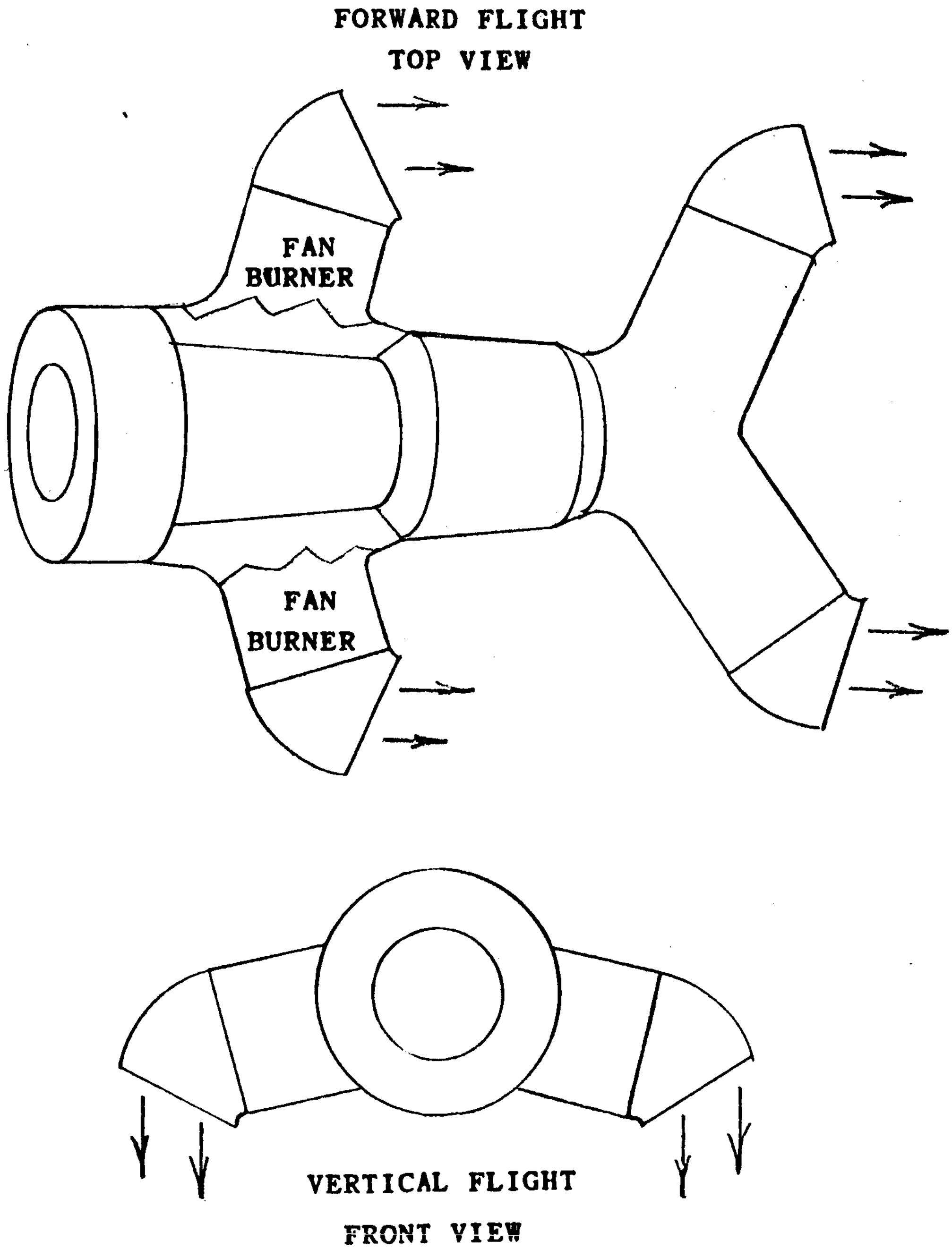
38. Plate 24 shows the effect of blockage (A_L/A_R) on efficiency when the percentage of air admission area in the primary zone is held constant. There is a small but continuous improvement as A_L/A_R decreases. On the basis of these results and the curves on plate 12, it would appear that, for a given burner design, the lowest pressure drop and the best performance cannot be had at a given ratio of A_L/A_R. A high overall performance, however, should make the combustion efficiency insensitive to this parameter.

39. Plate 25 shows the variation in space heat release rate with fuel/air ratio at 125 ft/sec for three combustors of different design. The highest value was achieved by burner 4B1, which also had the lowest pressure drop and the highest combustion efficiency at this velocity.

TABLE 2

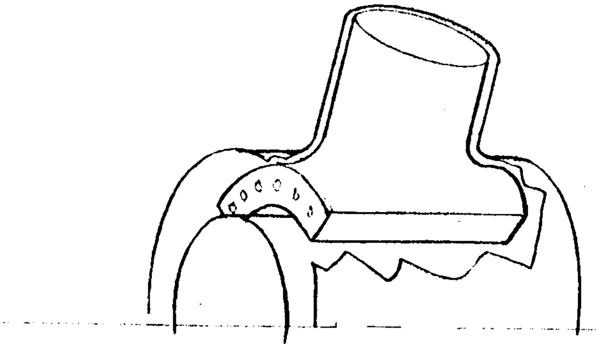
No.	Swirl Slot Shape	Overall Length Inches	Burner Cross Sectional Area Sq. Inches	Reference Area Sq. Inches	Total Hole Area Sq. Inches	Swirl Slot Area Sq. Inches	Secondary and Diluent Area Sq. Inches	Burner Volume Cu. Inches
1A		12.781	22.16	27.06	11.548	0.7020	9.852	262.5
1B		12.781	22.16	30.21	11.548	0.7020	9.852	262.5
3A		12.938	19.73	27.06	15.692	0.888	13.806	226.3
3B		12.938	19.73	30.21	15.692	0.888	13.806	226.3
1X		12.781	22.16	27.06	N.A.	0.7020	N.A.	323.2
4A		12.781	16.35	27.06	11.548	0.7020	9.852	170.7
4AA		12.781	16.35	27.06	12.178	1.3320	9.852	170.7
4A1		12.781	16.35	27.06	11.867	1.0212	9.852	170.7
4A2		12.781	16.35	27.06	12.178	1.3320	9.852	170.7
4A3		12.781	16.35	27.06	11.548	0.7020	9.852	170.7
4A4		12.781	16.35	27.06	12.580	1.7340	9.852	170.7
4A5		12.781	16.35	27.06	12.178	1.3320	9.852	170.7
4B1		12.781	16.35	27.06	15.777	1.3320	13.360	170.7
4B		12.781	16.35	30.21	15.147	0.7020	13.360	170.7
4B2		12.781	16.35	30.21	11.548	0.7020	9.852	170.7
4B3		12.781	16.35	30.21	N.A.	1.7340	N.A.	275.1
RAC-1		27.875	17.25	28.27	31.317	0.7030	26.507	440.0
J79	N.A. (1)	16.000	33.81	58.42	30.529	N.A.	19.708	453.3

(1) Not applicable

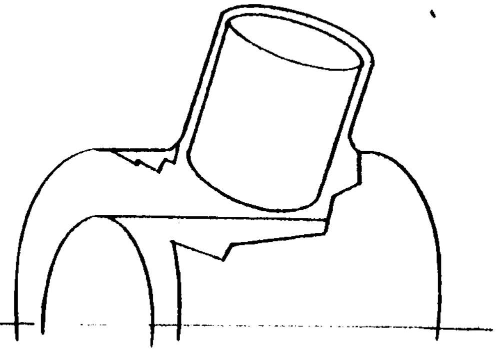


TYPICAL TURBOFAN ENGINE
CONFIGURED FOR V/STOL
WITH FAN BURNER

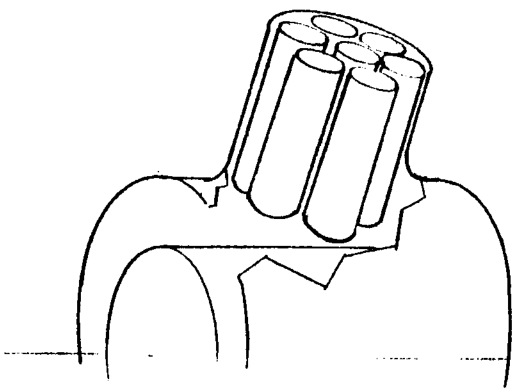
PLATE 1



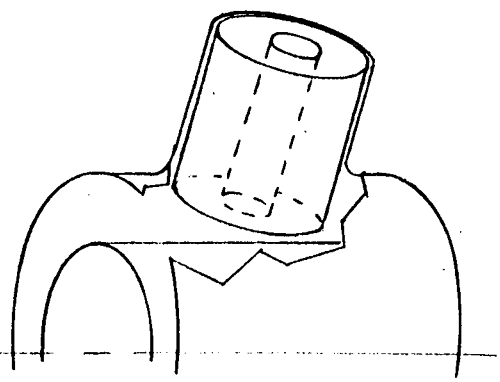
ANGLE COMBUSTOR



SINGLE CAN



MULTIPLE CAN

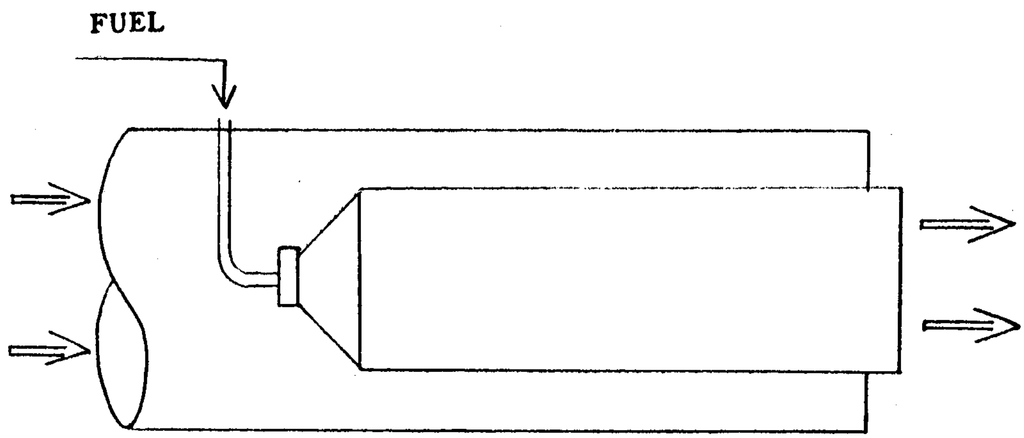


ANNULAR CAN

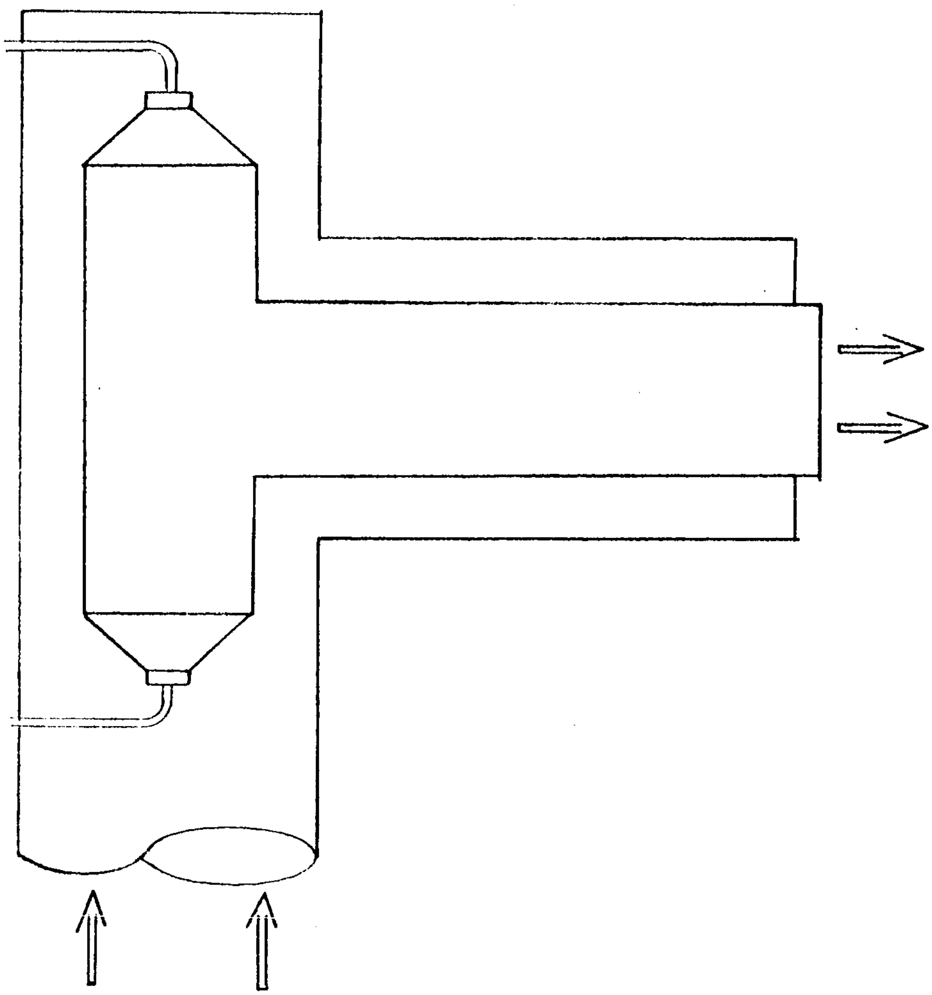
POSSIBLE CAN TYPE

COMBUSTOR SHAPES

PLATE 2



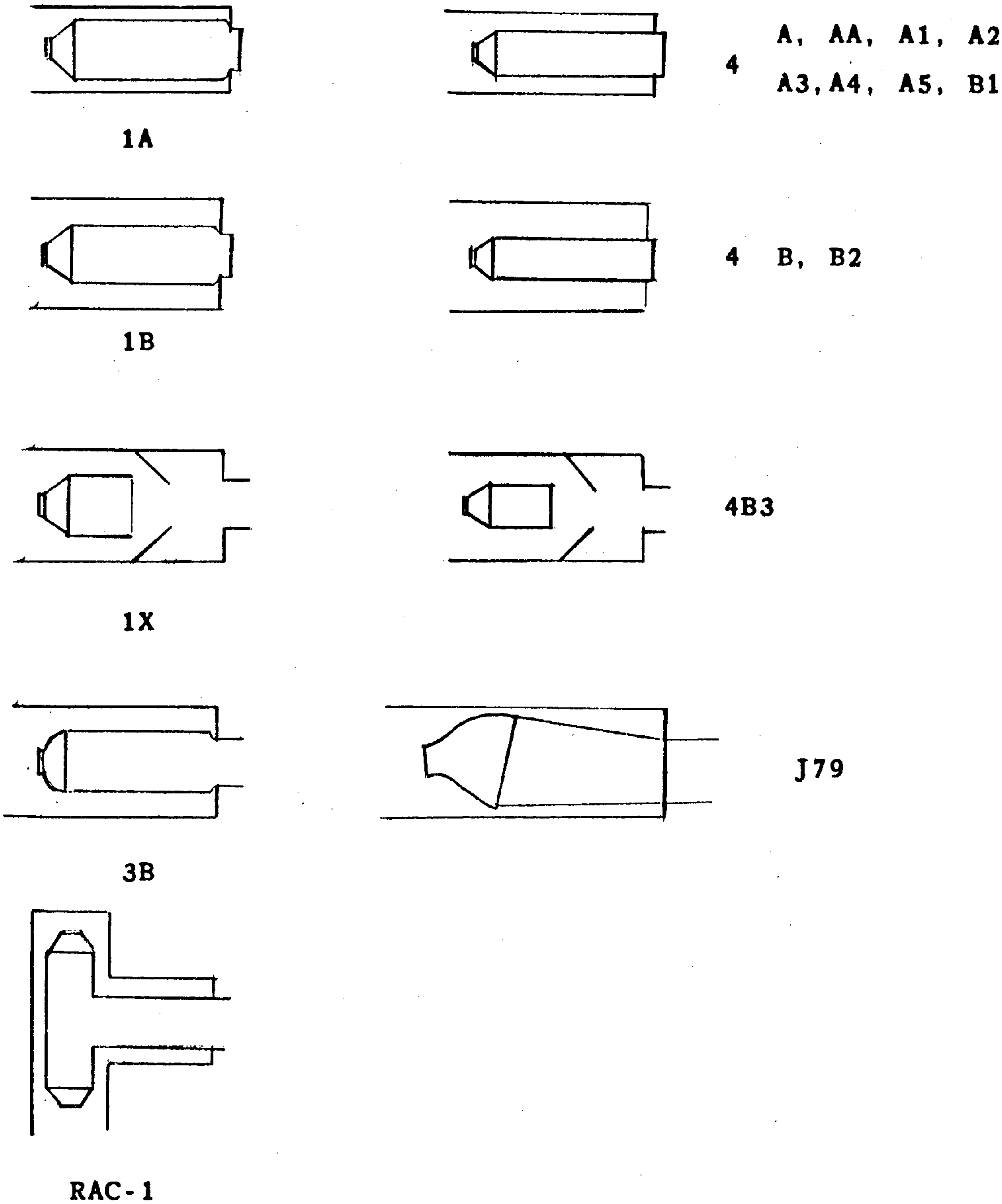
STRAIGHT THROUGH COMBUSTOR



RIGHT ANGLE COMBUSTOR

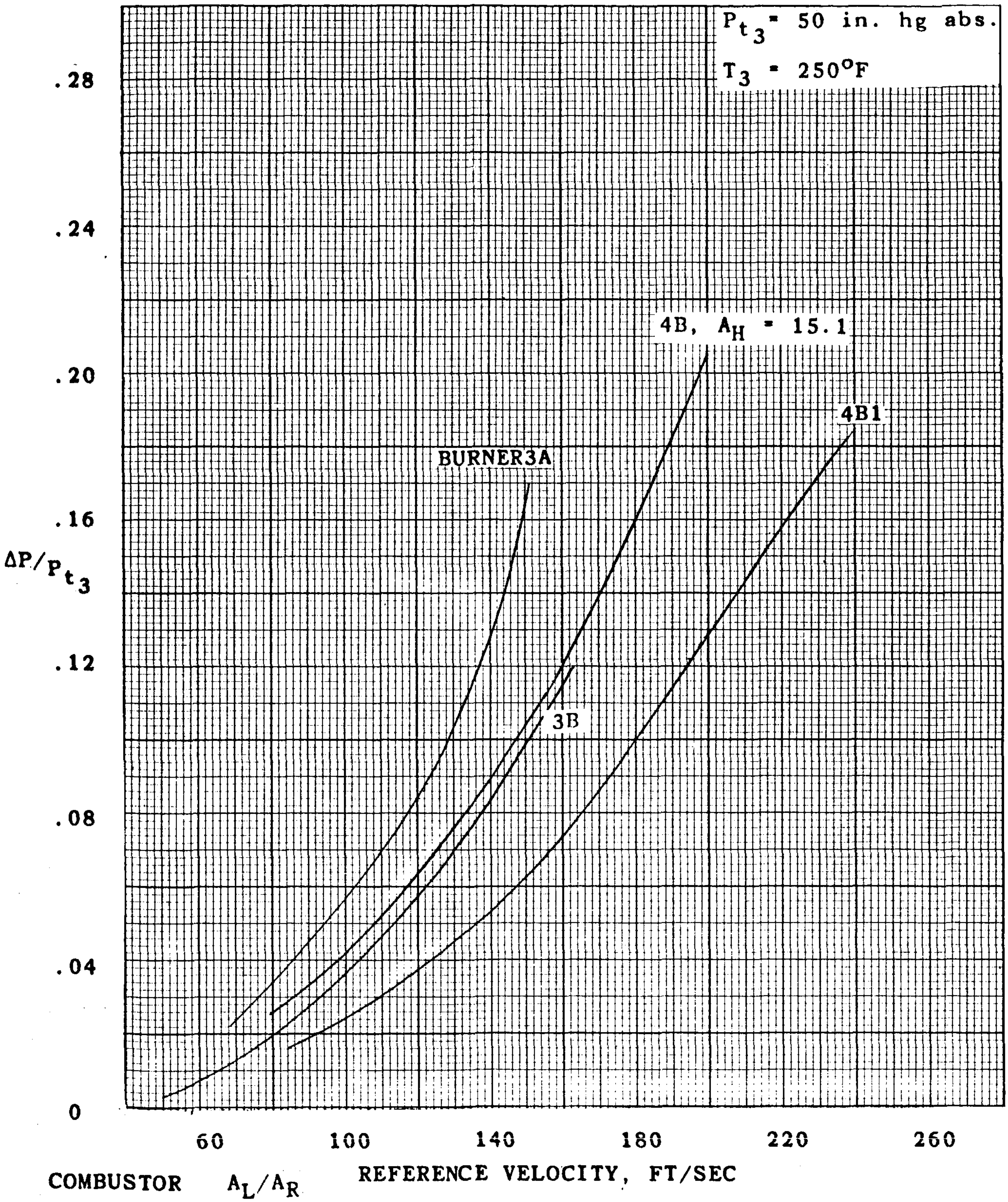
BASIC DESIGN OF
EXPERIMENTAL COMBUSTORS

PLATE 3



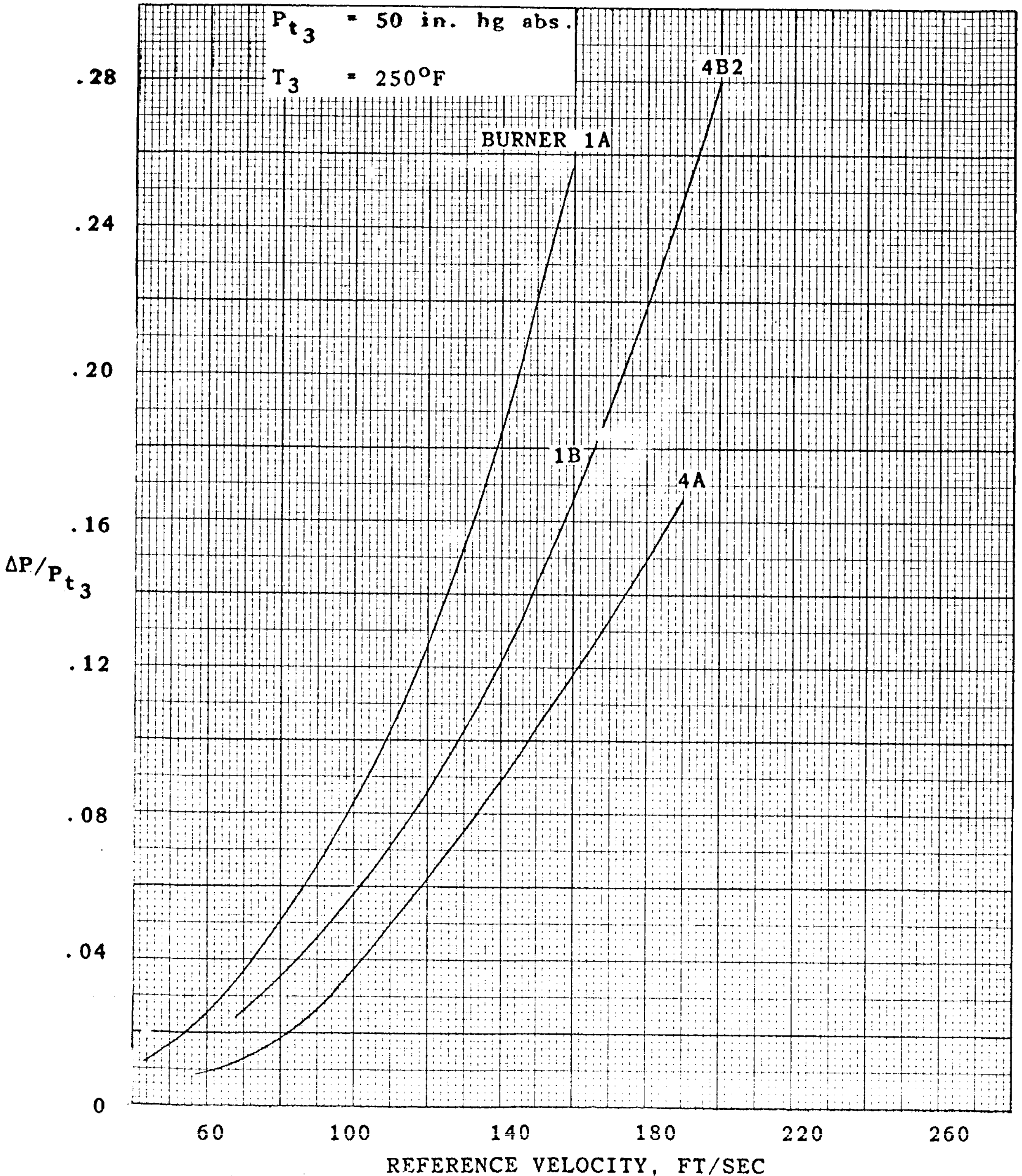
SCHEMATIC PRESENTATION
OF COMBUSTORS TESTED

PLATE 4



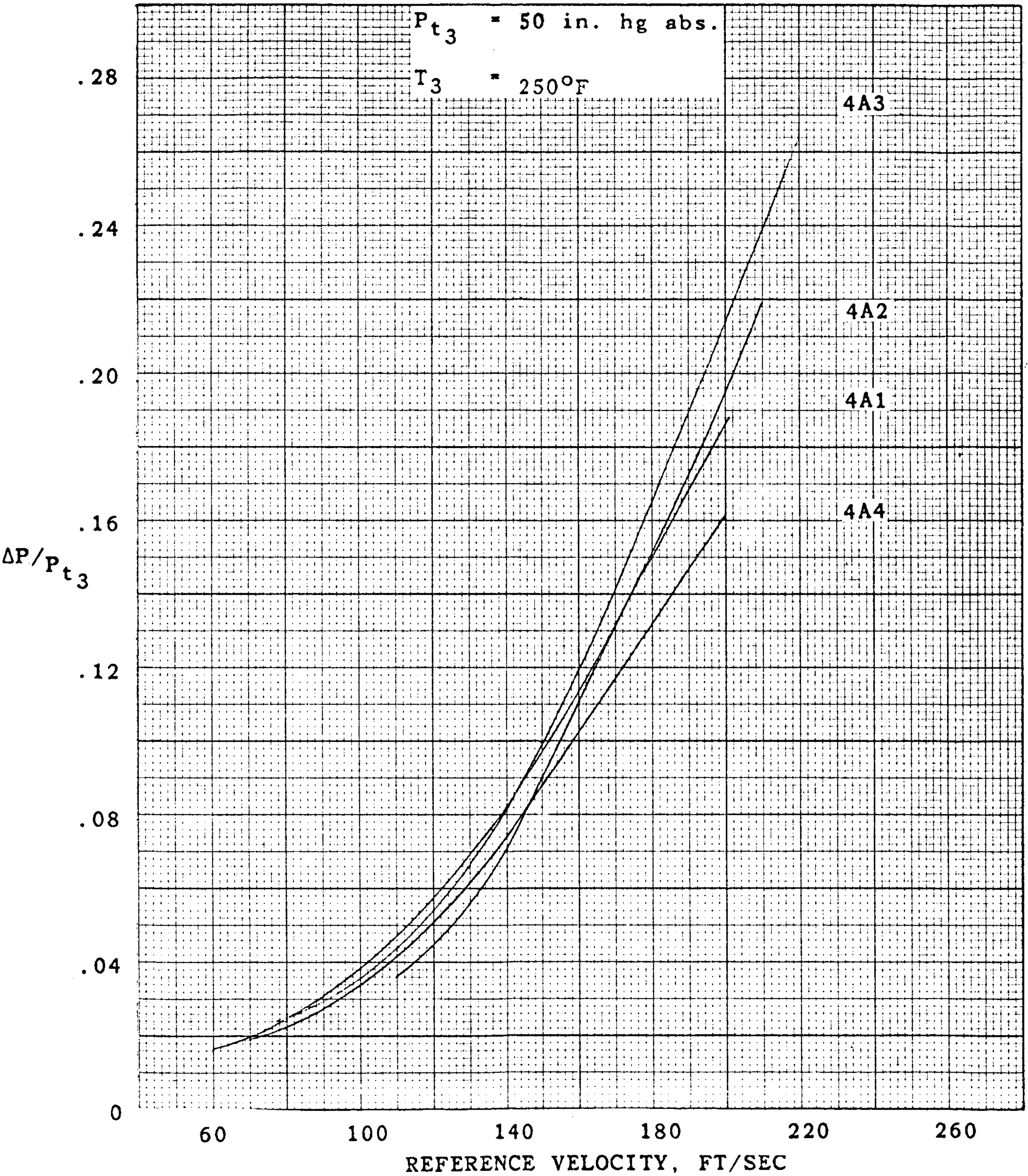
COMBUSTOR	A_L/A_R
3A	0.730
3B	0.655
4B1	0.605
4B	0.540

PRESSURE LOSS RATIO
VS. REFERENCE VELOCITY
EFFECT OF LINER TO REFERENCE
AREA RATIO $A_H = 15 \cdot 7$



COMBUSTOR	A_L/A_R
1A	0.817
1B	0.730
4A	0.605
4B2	0.540

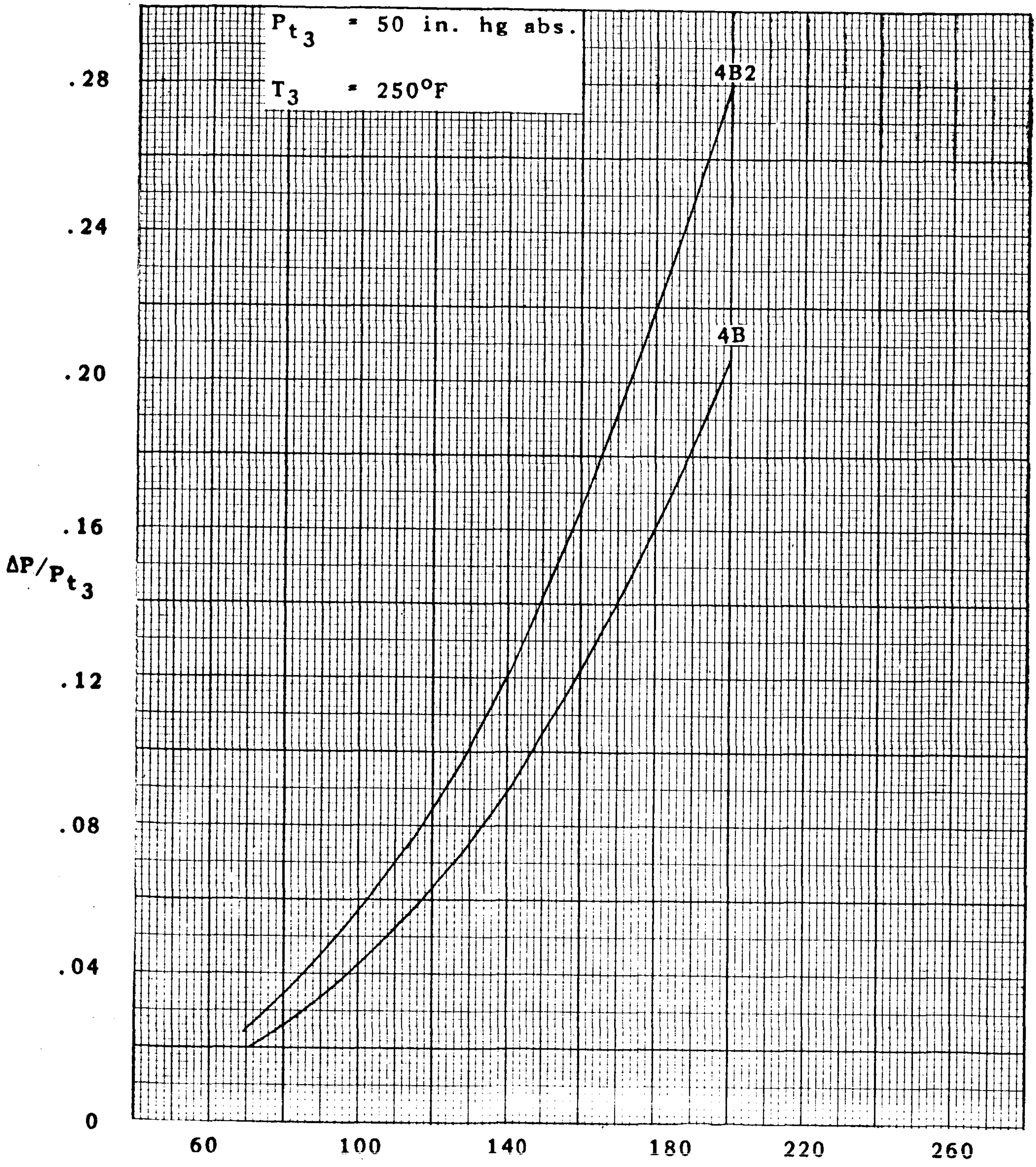
PRESSURE LOSS RATIO
VS REFERENCE VELOCITY
EFFECT OF LINER TO REFERENCE
AREA RATIO A_H = 11.5



COMBUSTOR	A_P/A_H
4A1	0.438
4A2	0.450
4A3	0.426
4A4	0.465

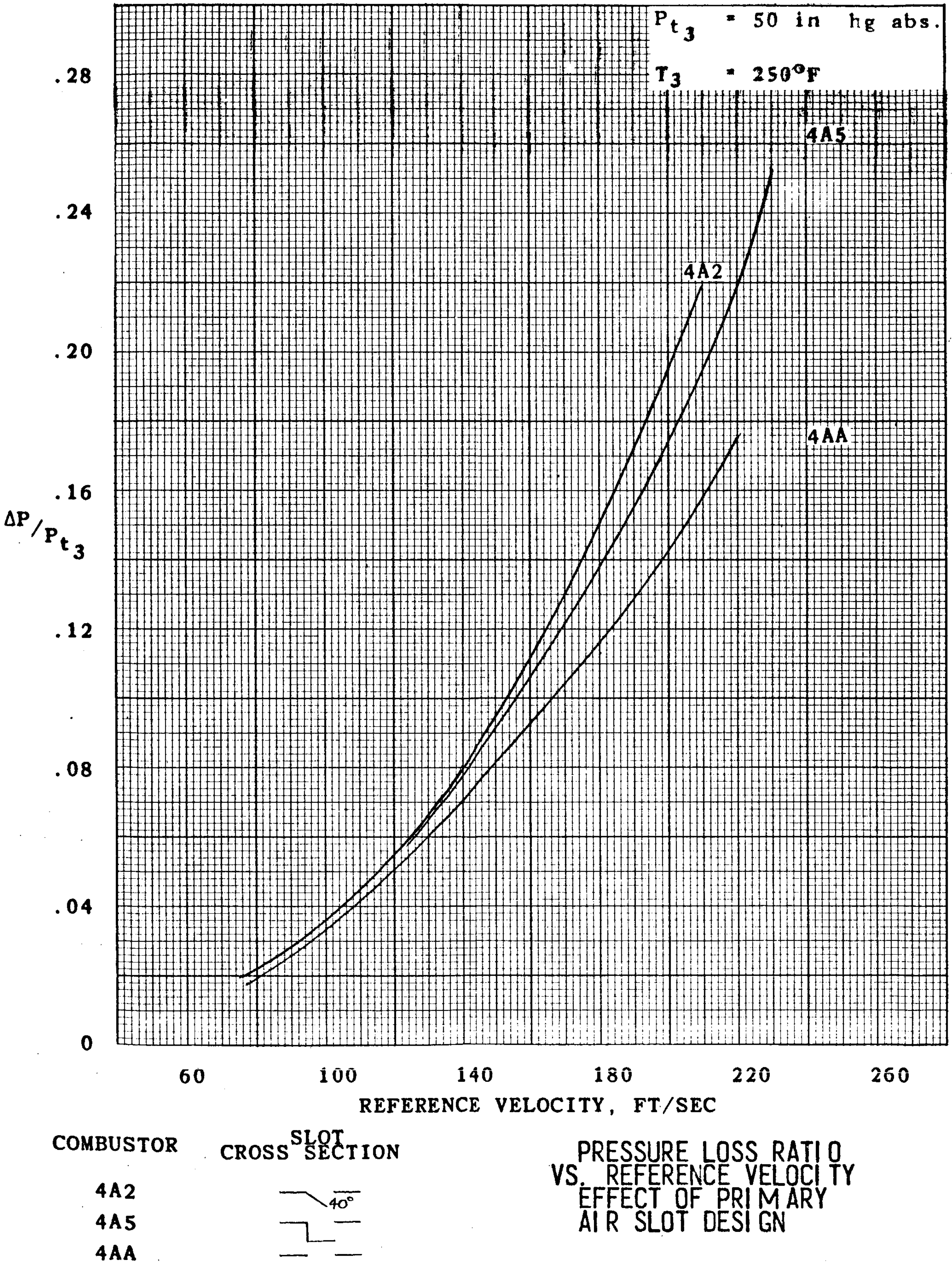
PRESSURE LOSS RATIO
VS. REFERENCE VELOCITY
EFFECT OF PRIMARY SWIRL
SLOT AREA CHANGE

PLATE 7

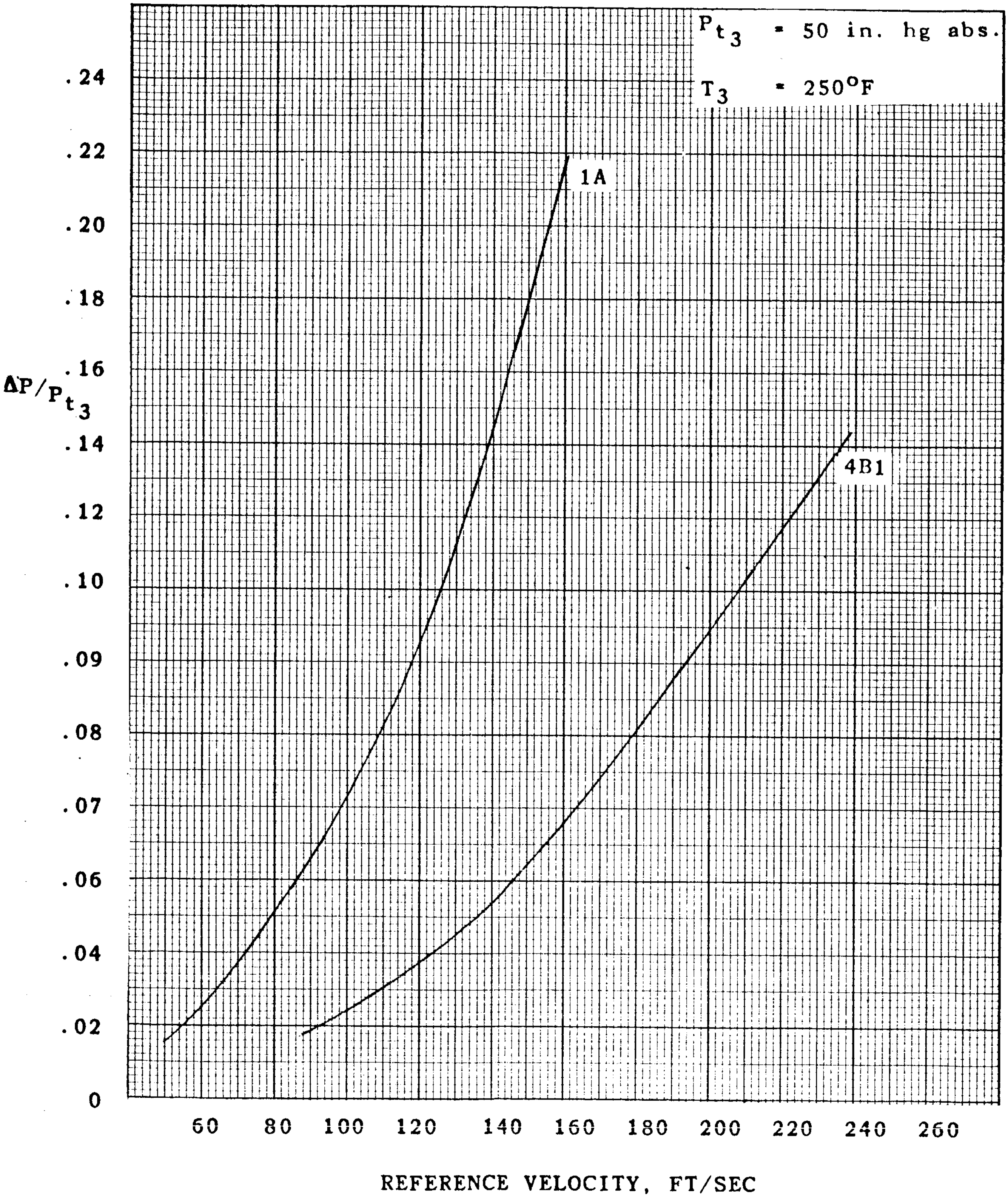


COMBUSTOR	HOLE AREA SQ. IN.	A_P/A_H
4B	15.147	.120
4B2	11.548	.147

PRESSURE LOSS RATIO
VS REFERENCE VELOCITY
EFFECT OF DILUENT
HOLE AREA CHANGE

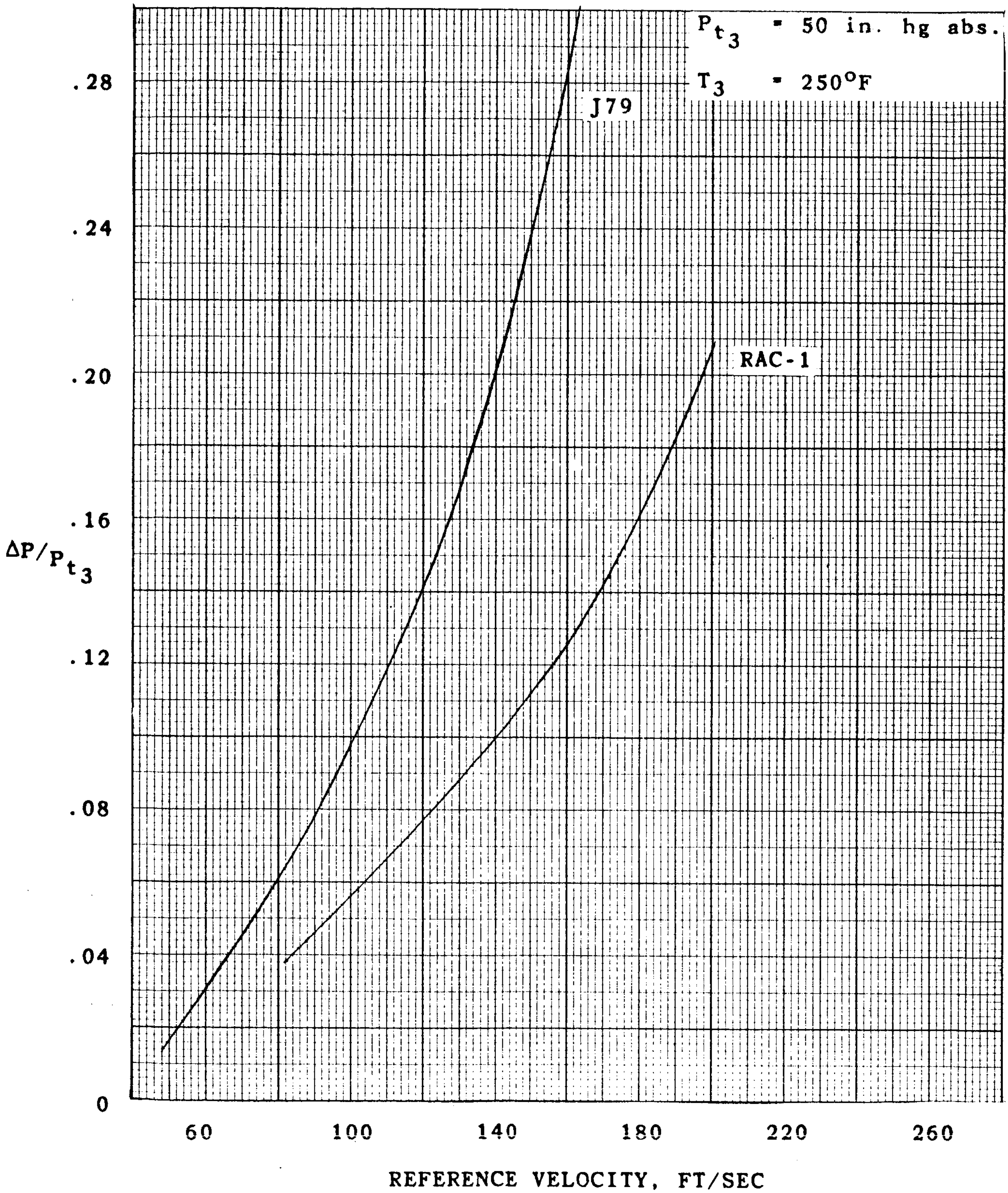


PRESSURE LOSS RATIO
VS. REFERENCE VELOCITY
EFFECT OF PRIMARY
AIR SLOT DESIGN



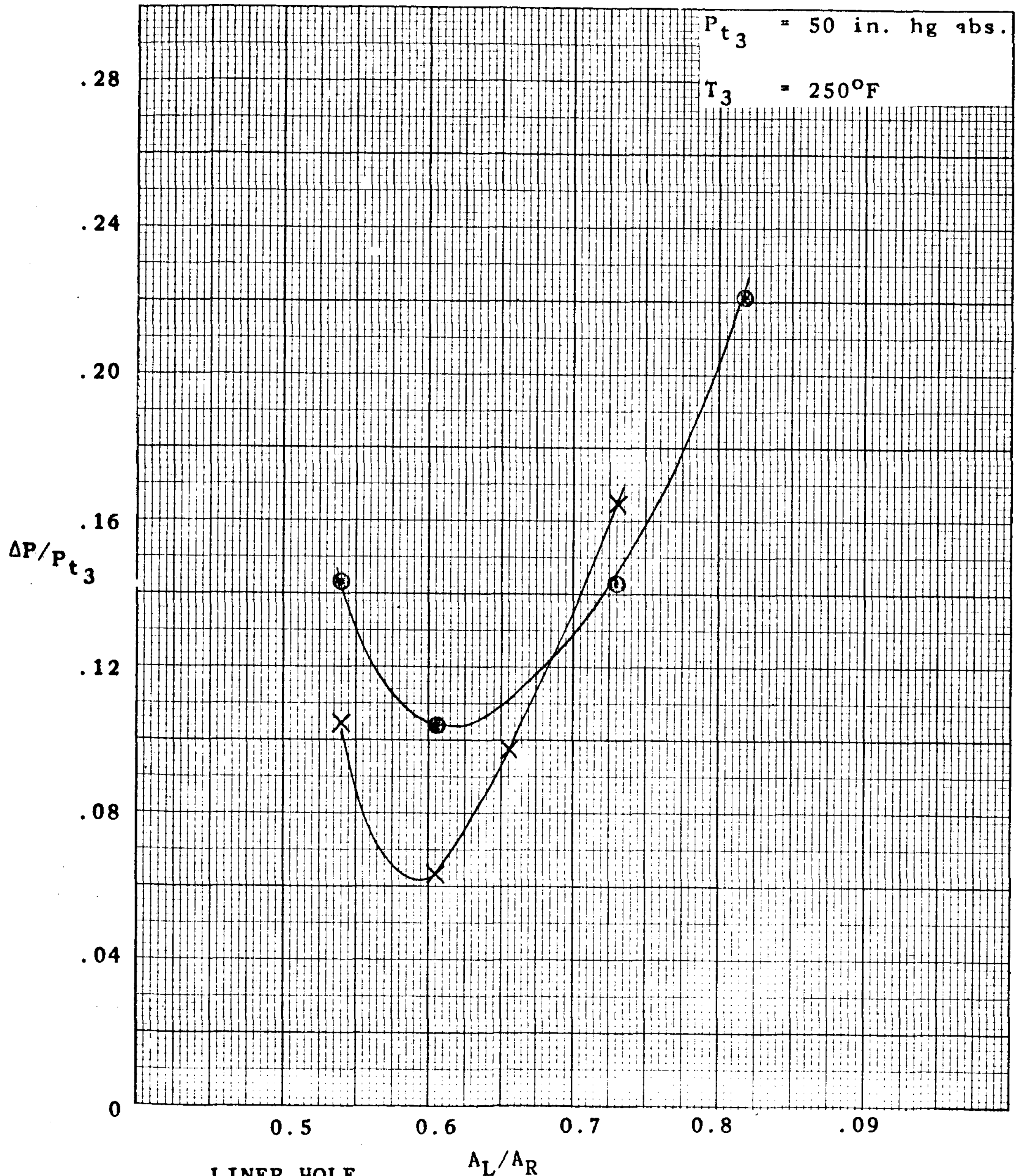
PRESSURE LOSS RATIO
VS REFERENCE VELOCITY

PLATE 10



PRESSURE LOSS RATIO
VS REFERENCE VELOCITY

PLATE 11

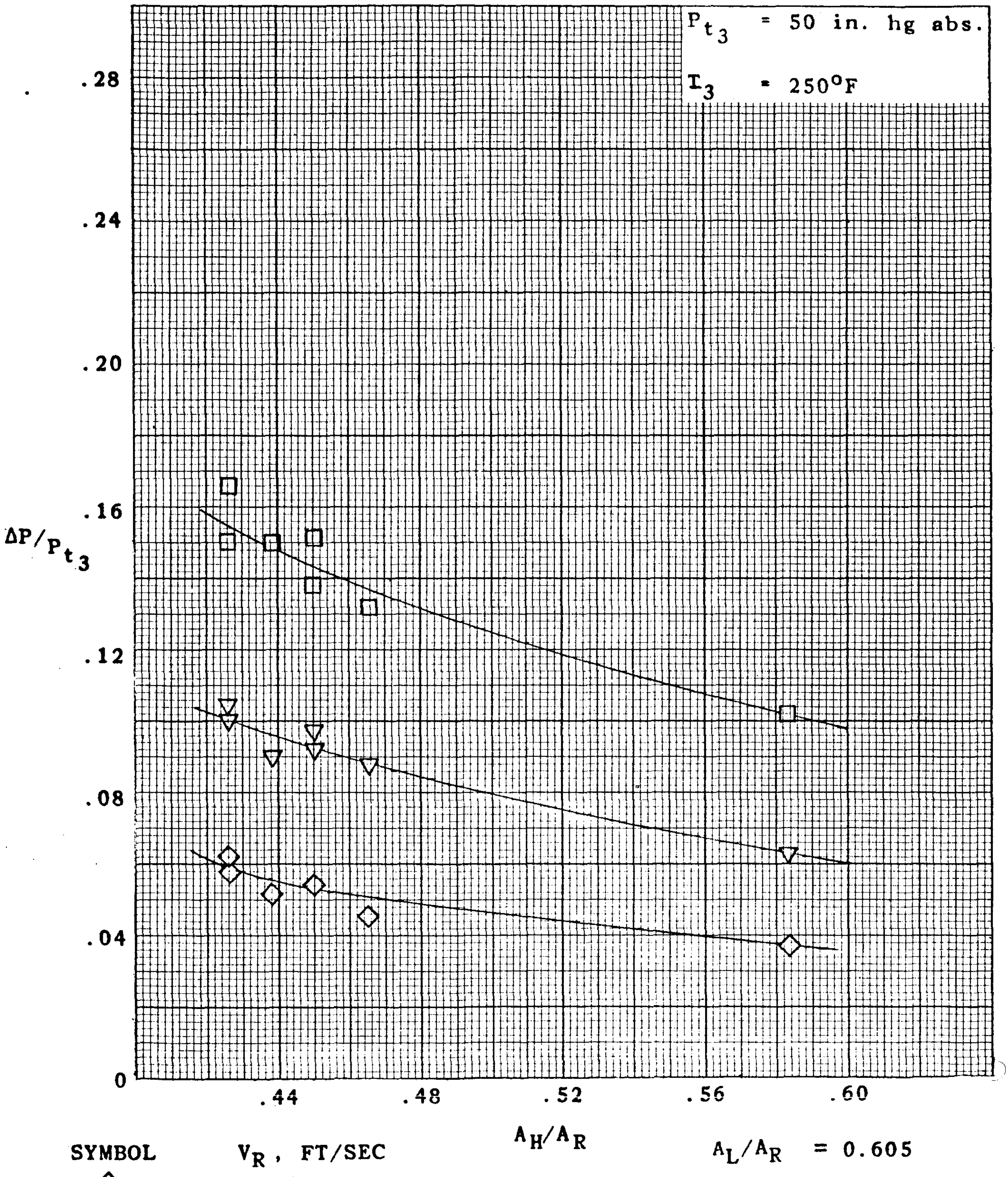


SYMBOL	LINER HOLE AREA, SQ/IN.
×	15.7
⊛	11.5

EFFECT OF LINER TO REFERENCE AREA RATIO ON COMBUSTOR PRESSURE LOSS

V_R = 150 Ft/Sec

PLATE 12

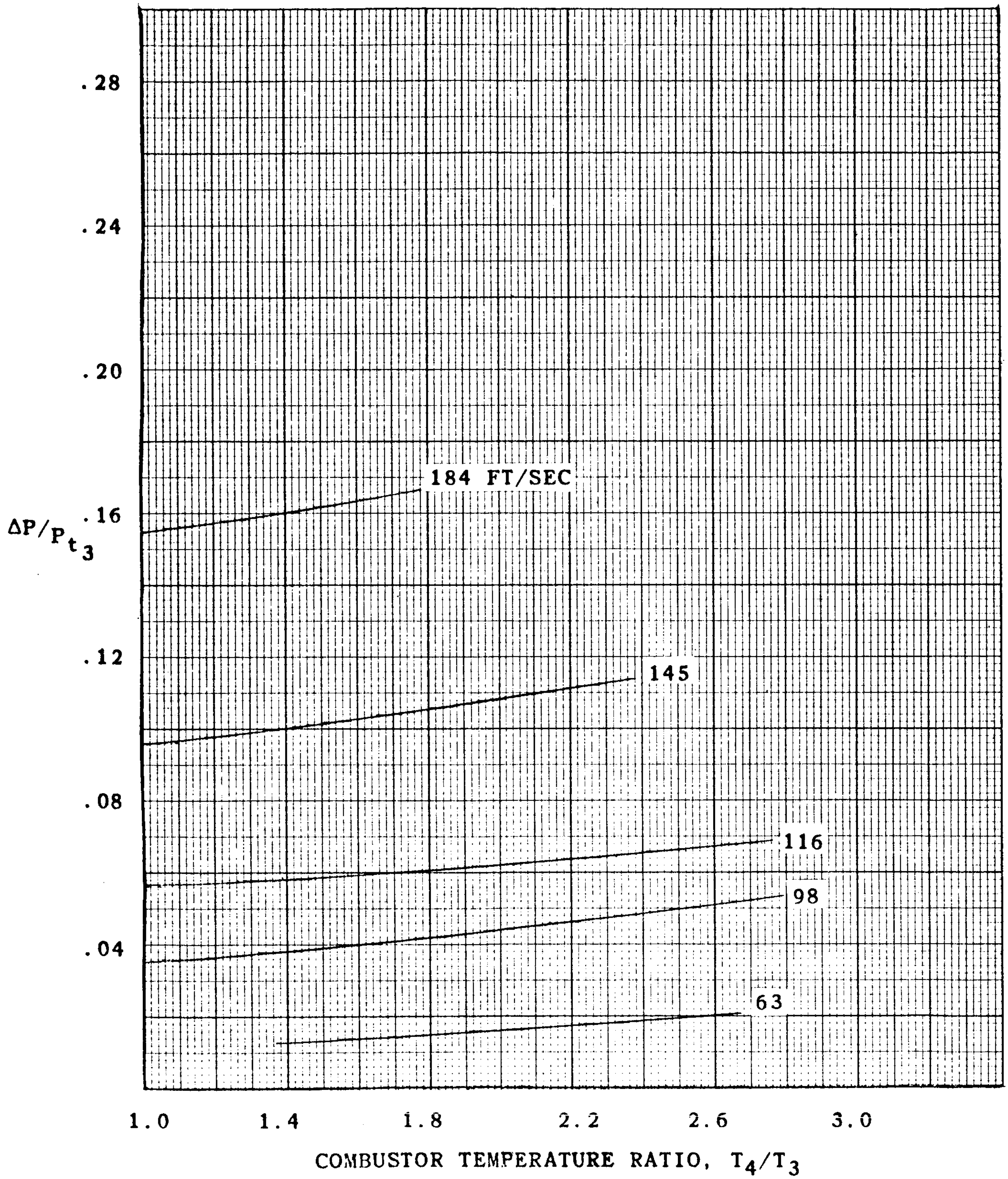


SYMBOL | V_R, FT/SEC
◇ 120
▽ 150
□ 180

A_L/A_R = 0.605

EFFECT OF AIR ADMISSION HOLE AREA ON COMBUSTOR PRESSURE LOSS

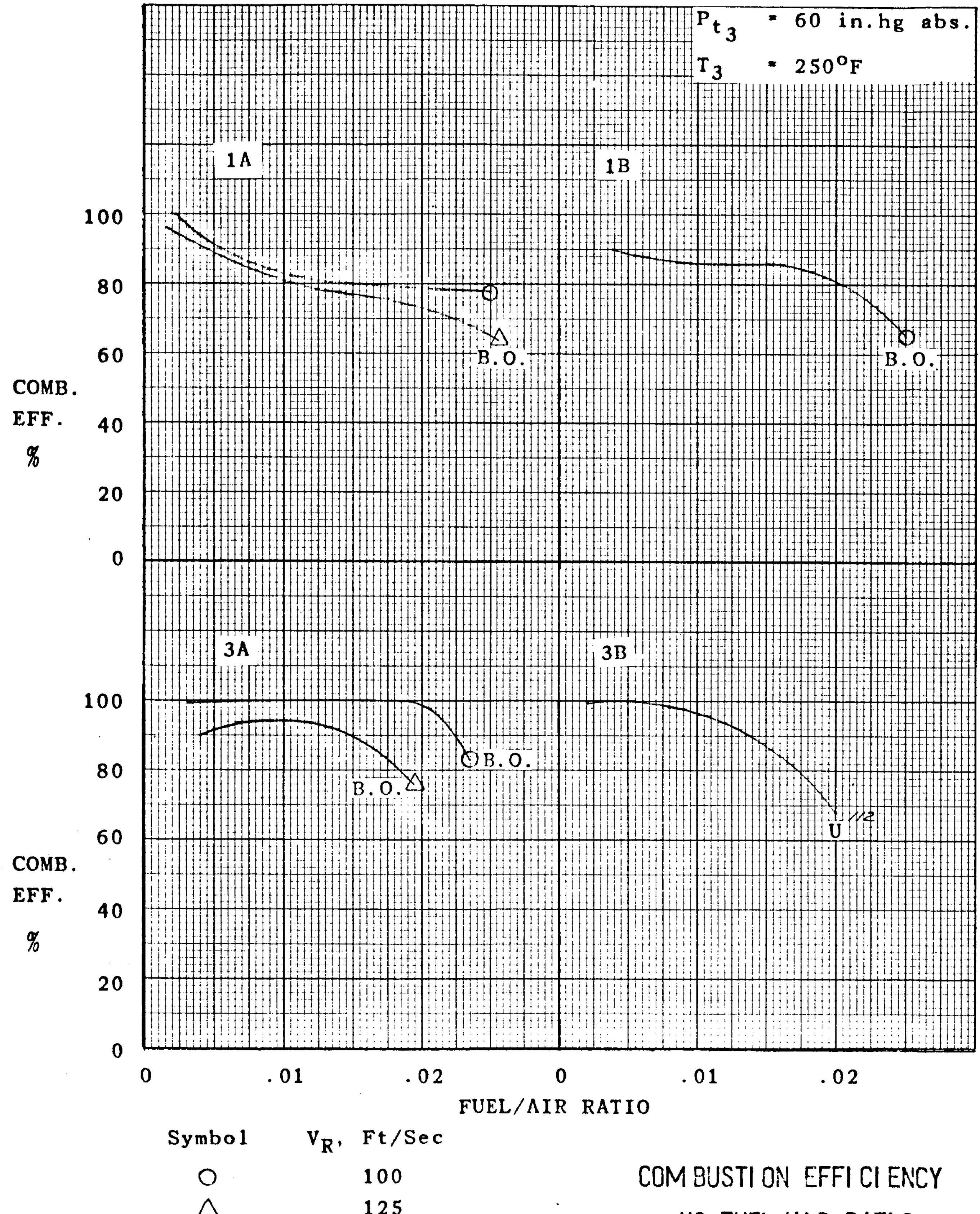
PLATE 13



P_{t_3} = 60 in.hg abs.

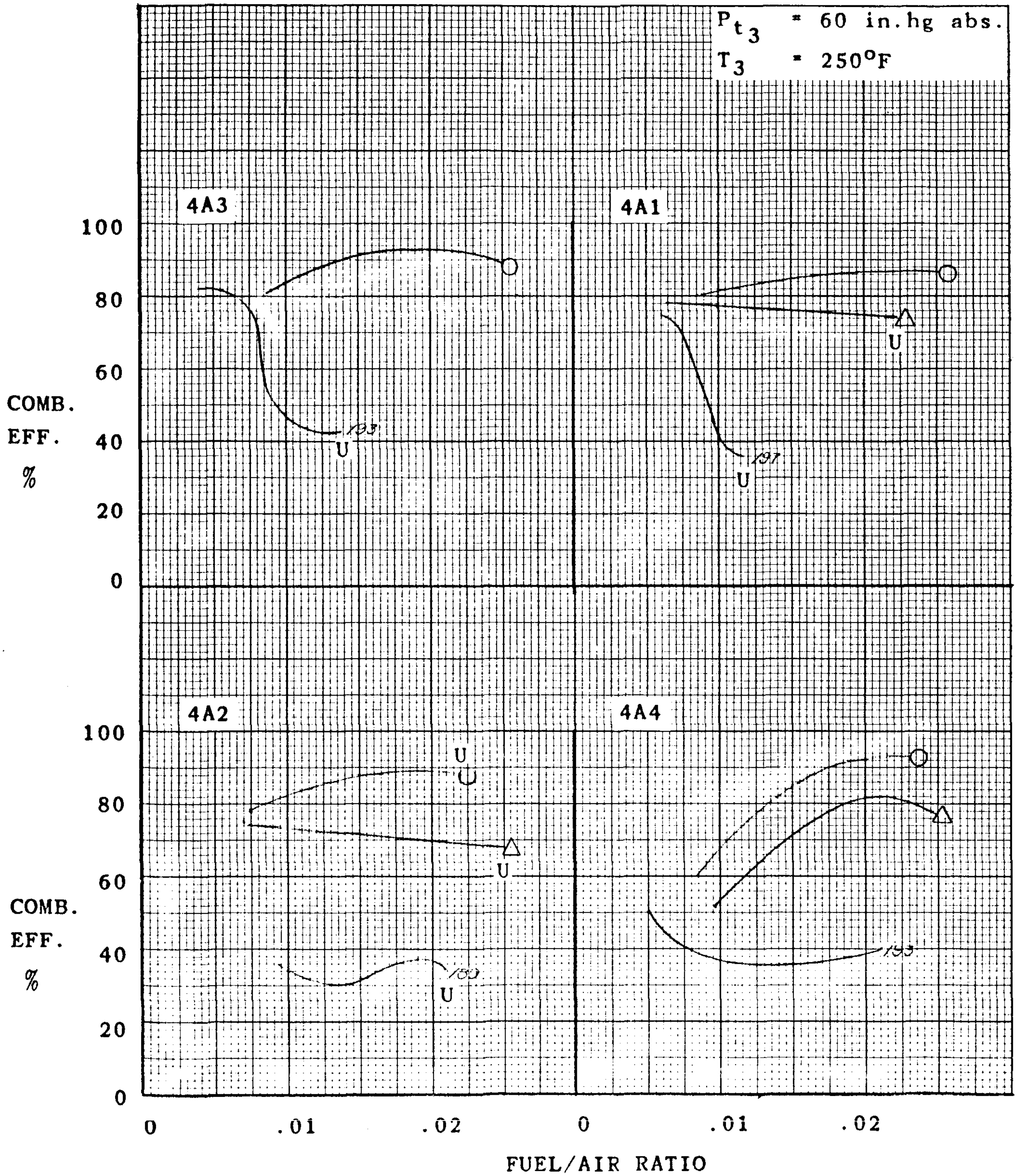
T_3 = 250°F

EFFECT OF COMBUSTOR TEMPERATURE RISE ON TOTAL PRESSURE LOSS



COMBUSTION EFFICIENCY VS FUEL/AIR RATIO

PLATE 15

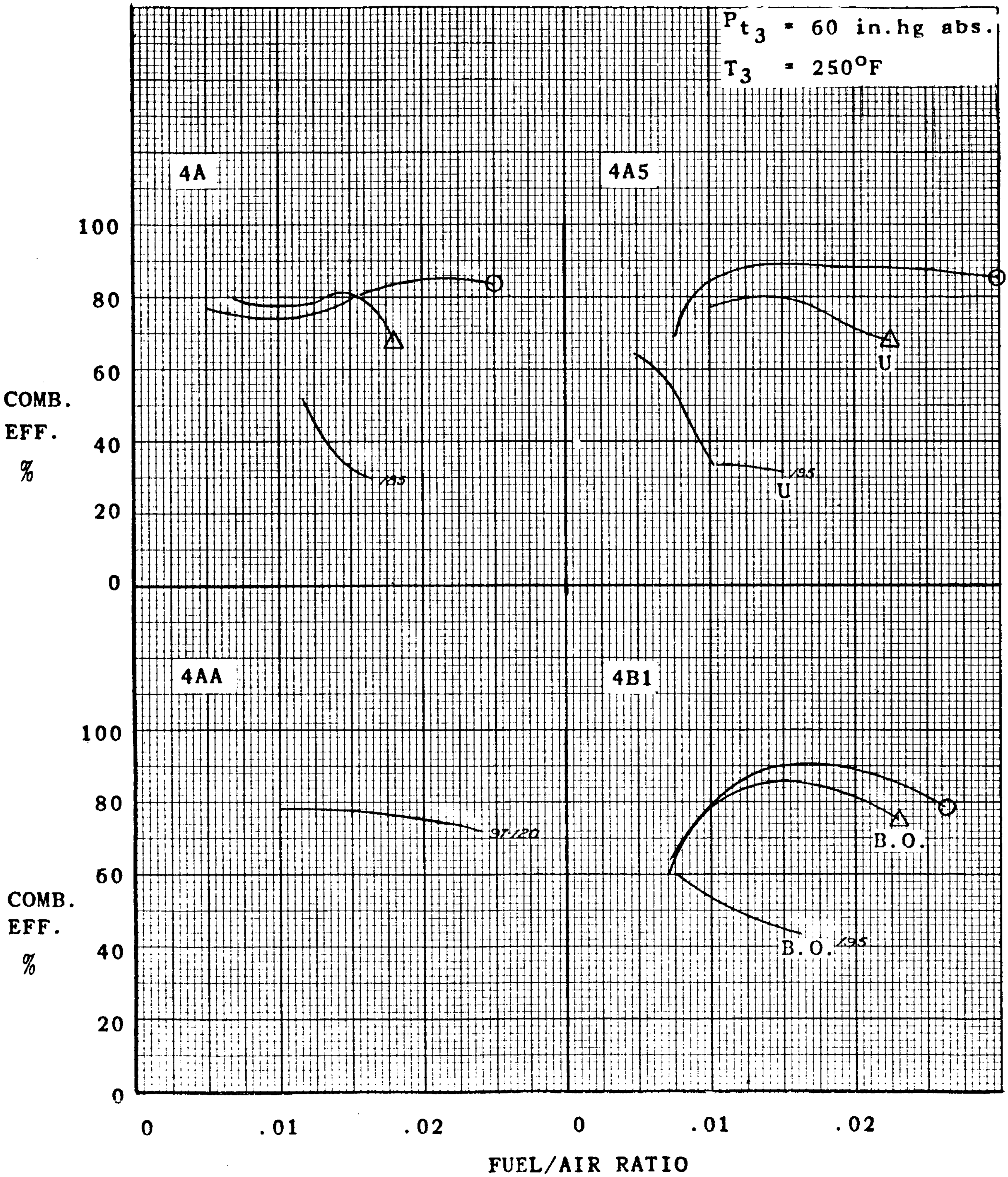


Symbol	V_R, Ft/Sec
○	100
△	125

COMBUSTION EFFICIENCY

VS FUEL/AIR RATIO

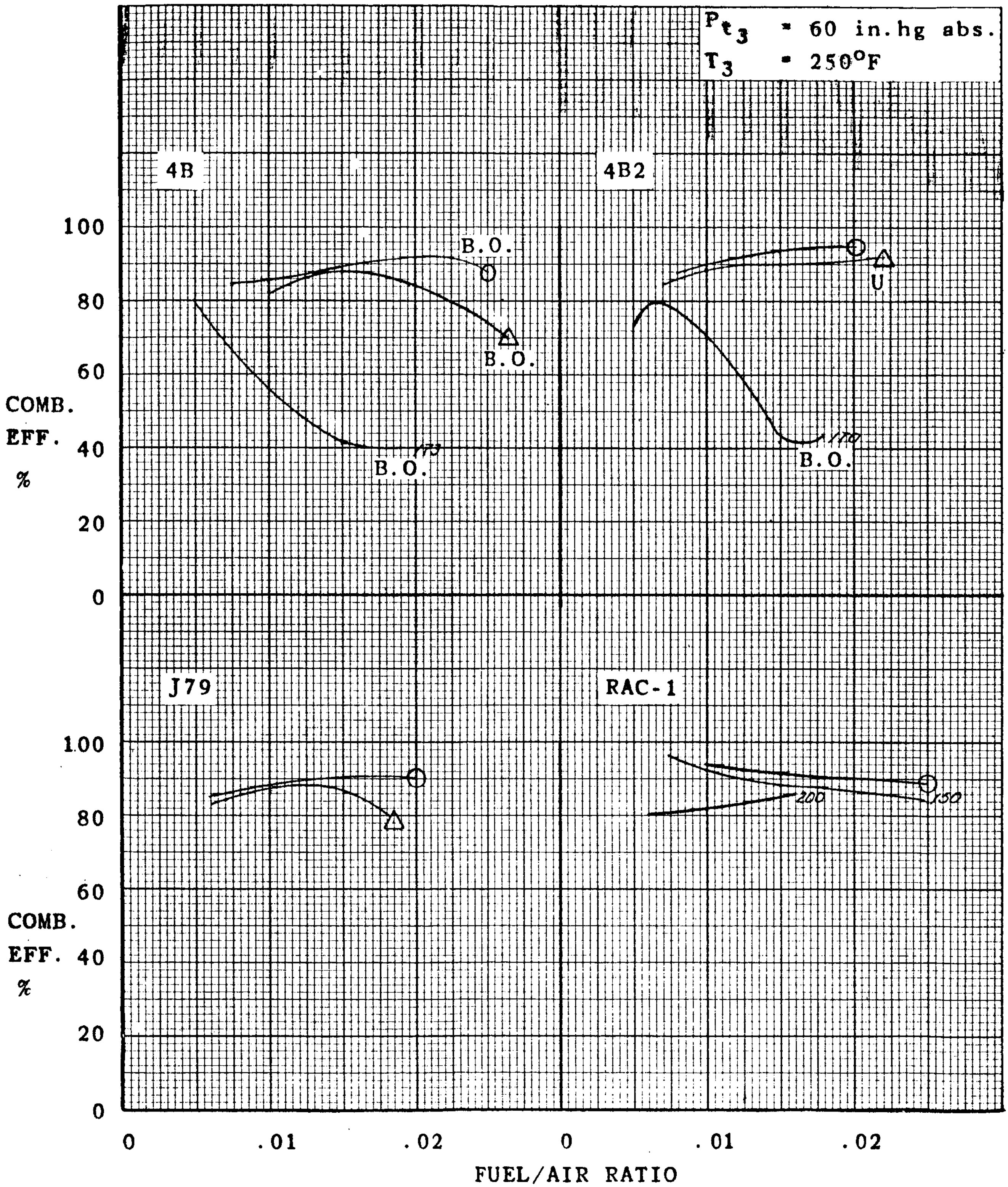
PLATE 16



Symbol	V_R, Ft/Sec
○	100
△	125

COMBUSTION EFFICIENCY VS FUEL/AIR RATIO

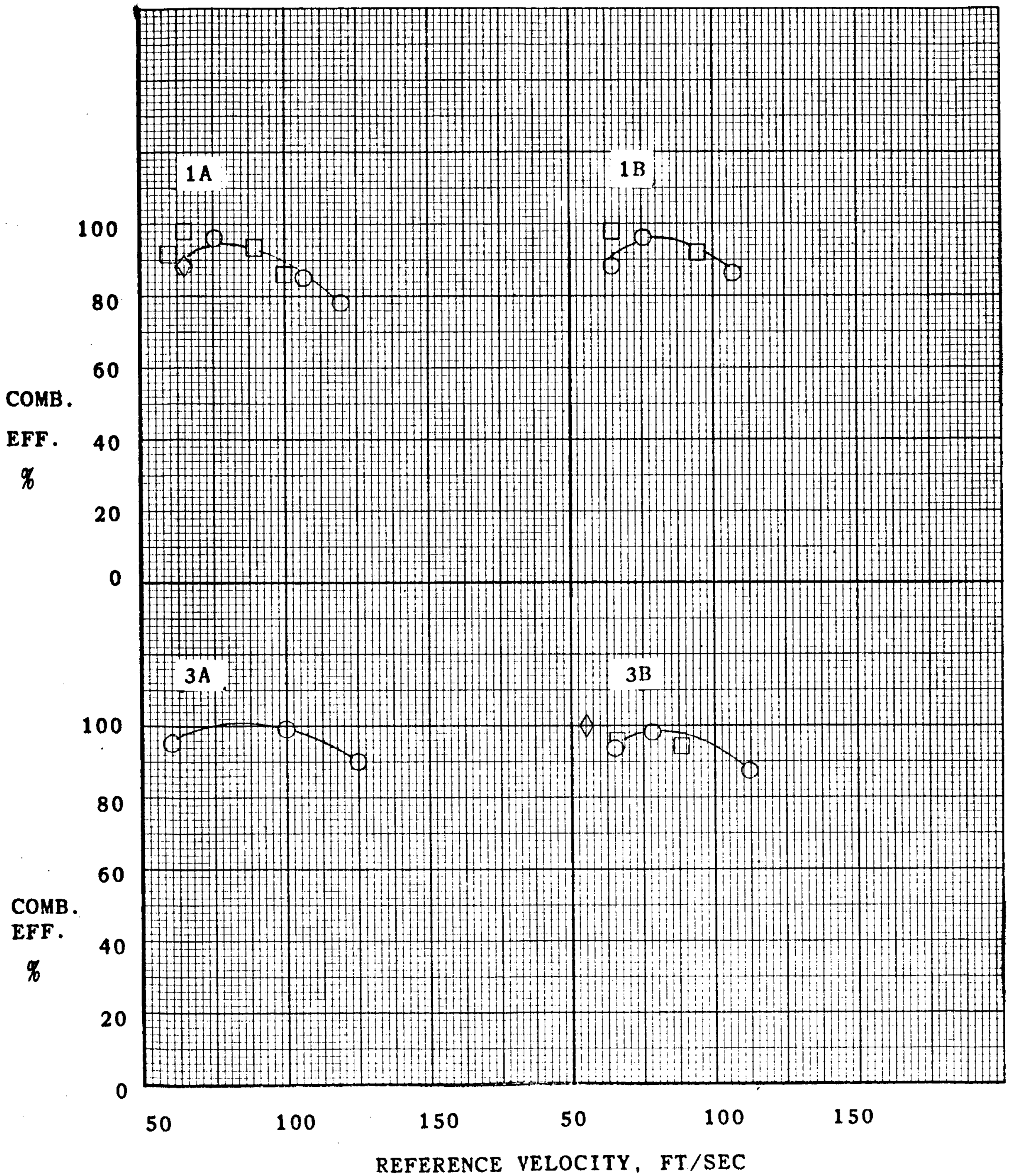
PLATE 17



Symbol	V_R, Ft/Sec
○	100
△	125

COMBUSTION EFFICIENCY
VS FUEL/AIR RATIO

PLATE 18

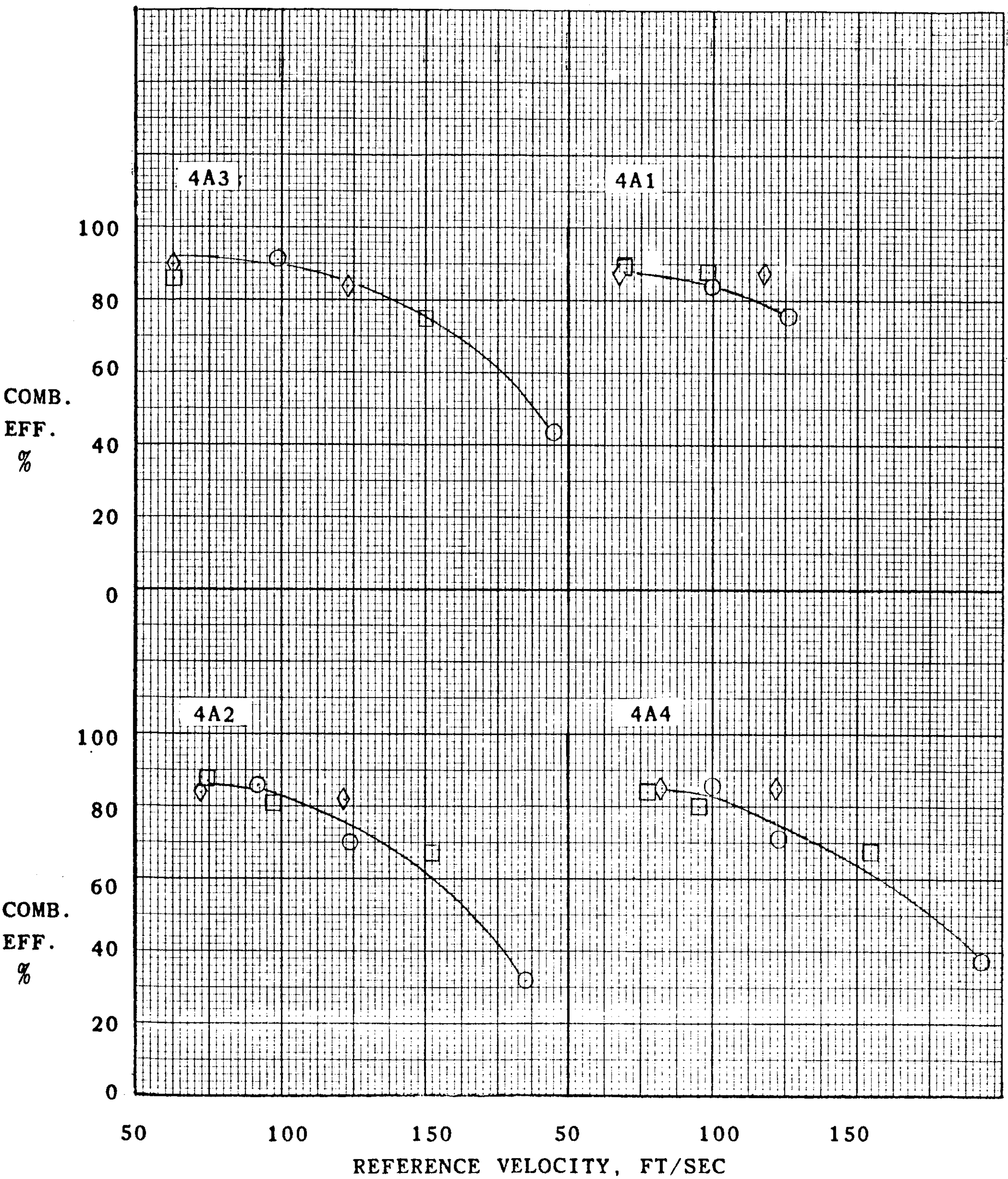


Symbol	P_{t_3}, In. Hg
○	60
□	75
◇	90

COMBUSTION EFFICIENCY VS REFERENCE VELOCITY

$T_3 = 250^{\circ}F$

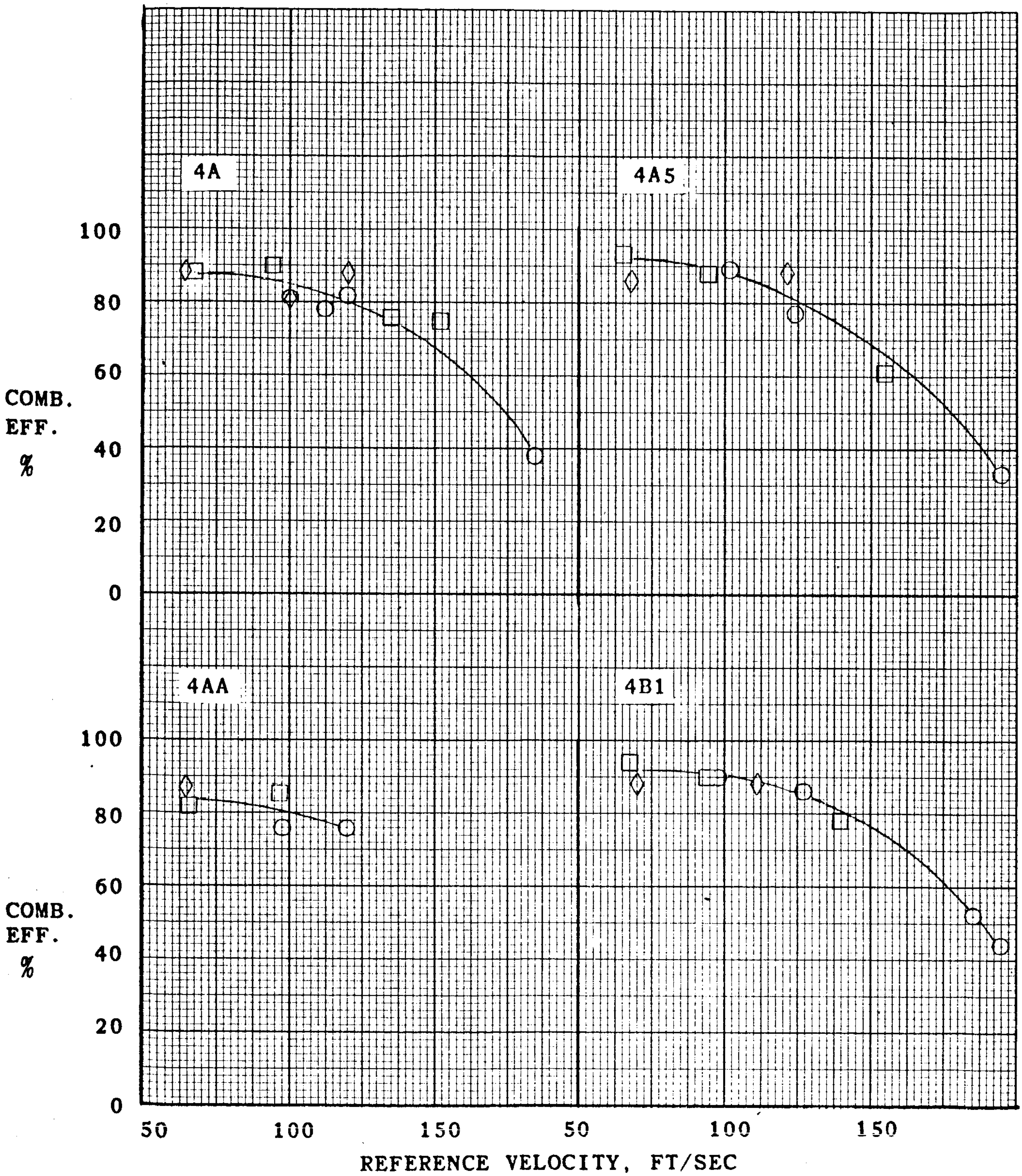
PLATE 19



Symbol	P_{t_3}, In. Hg
○	60
□	75
◇	90

COMBUSTION EFFICIENCY
VS REFERENCE VELOCITY
$T_3 = 250^{\circ}F$

PLATE 20

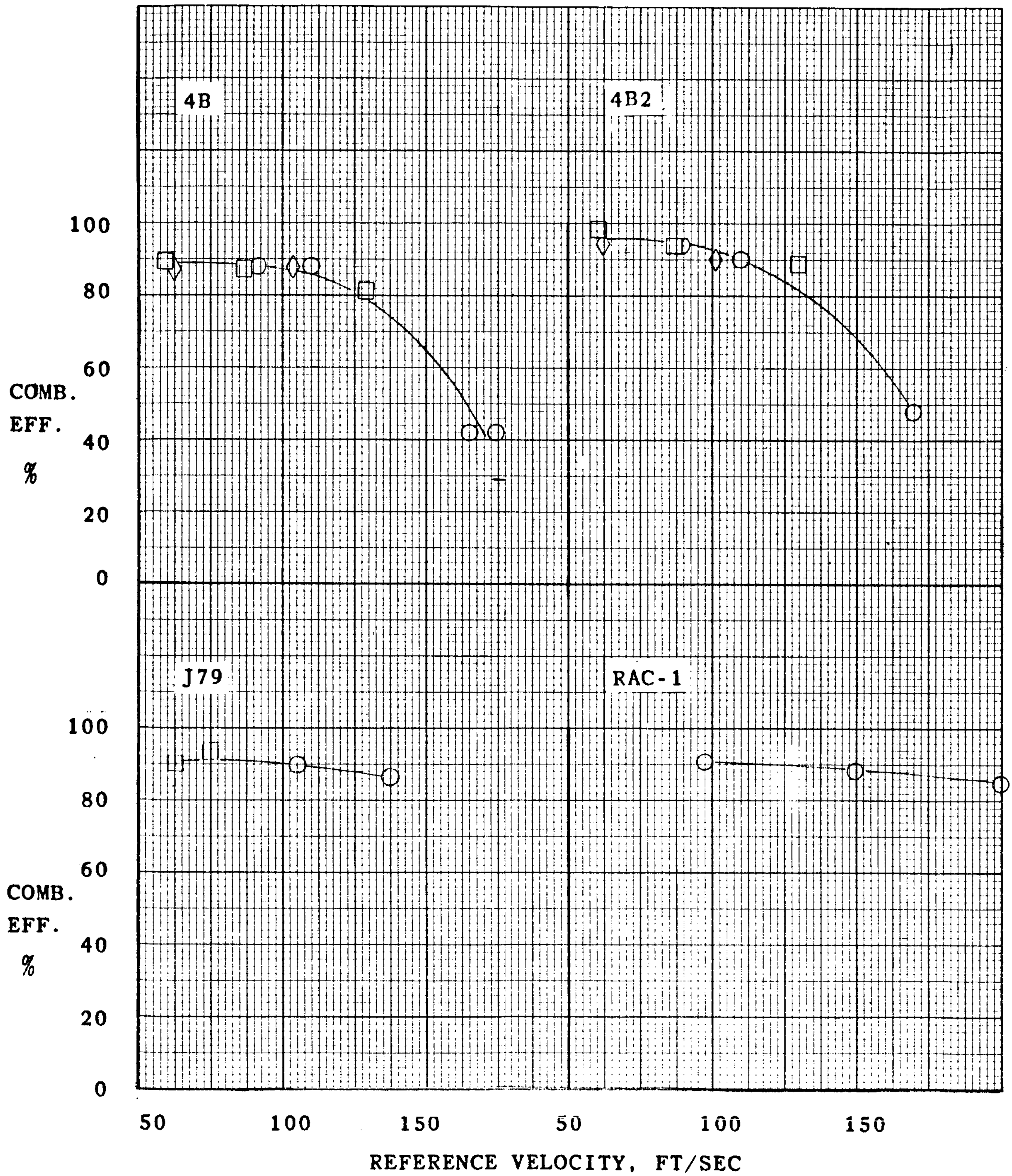


Symbol	P_{t_3}, In. Hg
○	60
□	75
◇	90

COMBUSTION EFFICIENCY VS REFERENCE VELOCITY

$T_3 = 250^oF$

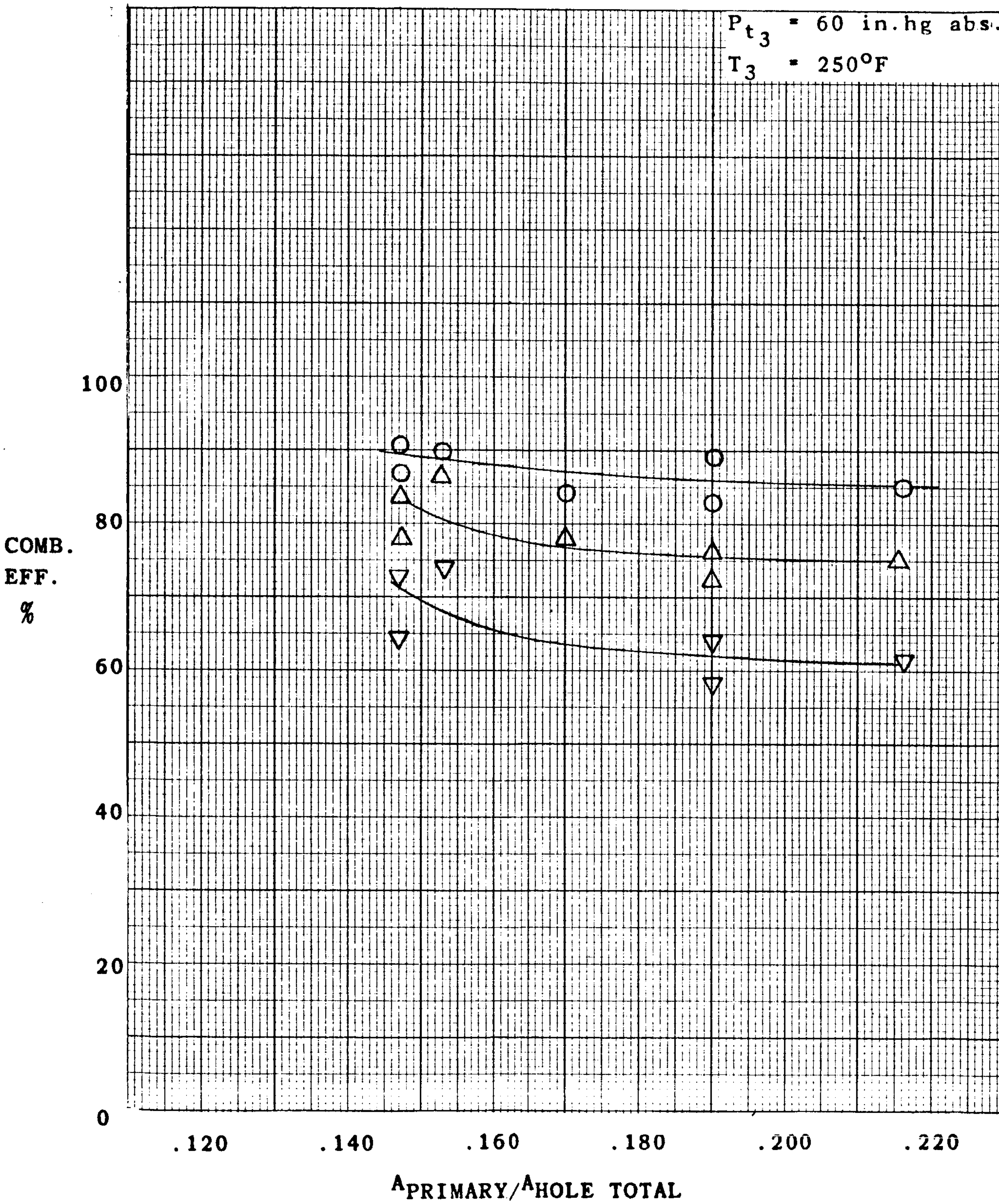
PLATE 21



Symbol	P_{t_3}, In. Hg
○	60
□	75
◇	90

COMBUSTION EFFICIENCY
VS REFERENCE VELOCITY
$T_3 = 250^{\circ}F$

PLATE 22

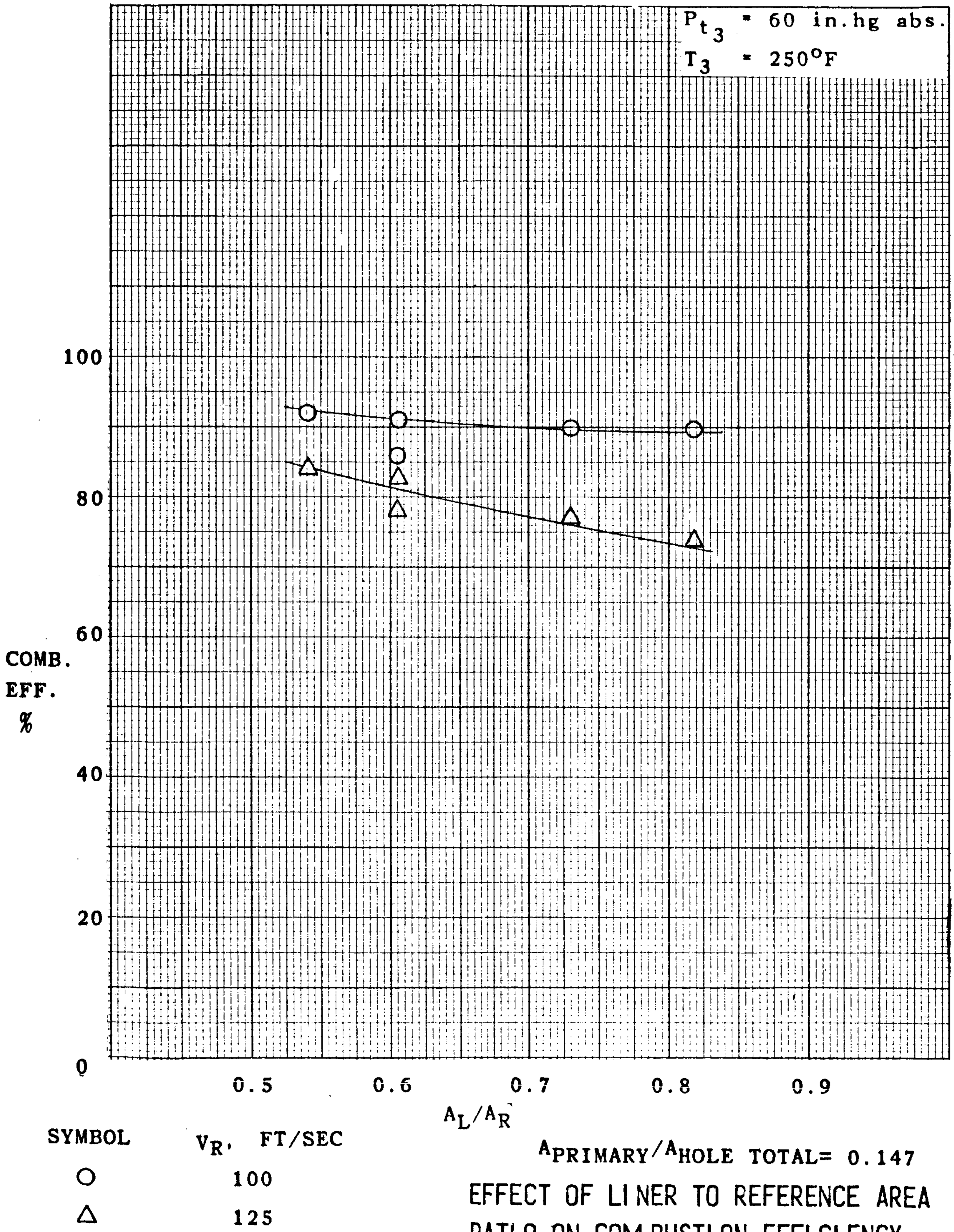


SYMBOL	V_R, FT/SEC
○	100
△	125
▽	15-0

A_L/A_R = 0.605
f/a = 0.015

EFFECT OF PRIMARY HOLE AREA ON COMBUSTION EFFICIENCY

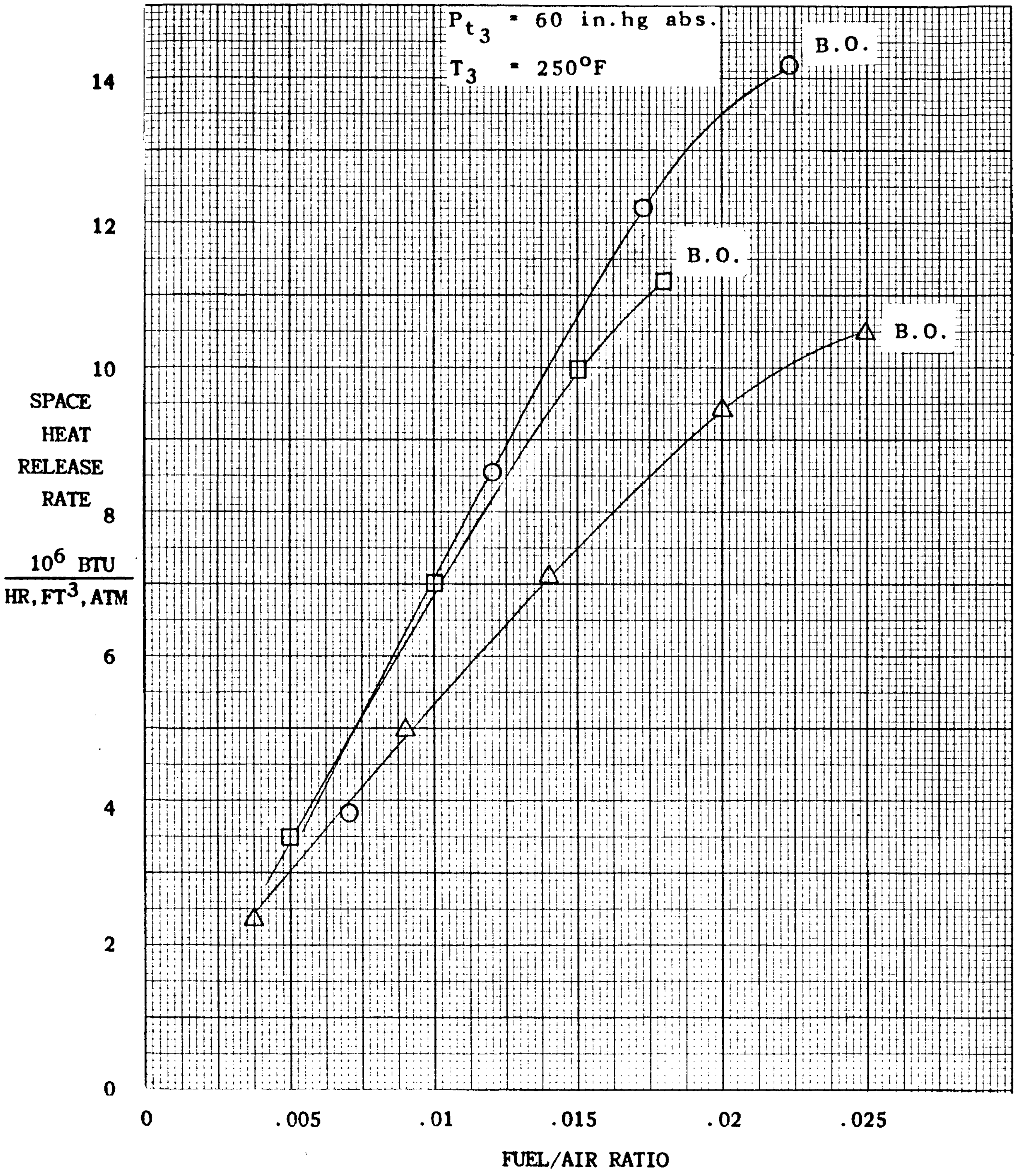
PLATE 23



$A_{PRIMARY}/A_{HOLE\ TOTAL}$= 0.147

EFFECT OF LINER TO REFERENCE AREA RATIO ON COMBUSTION EFFICIENCY

PLATE 24



SYMBOL	COMBUSTOR
△	1A
□	3A
○	$4B_1$

VARIATION IN SPACE HEAT RELEASE RATE WITH FUEL/AIR RATIO

V_R = 125 Ft/Sec

PLATE 25

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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13. ABSTRACT

A research program was initiated, under NASA sponsorship, on combustion in the fan duct of a turbofan engine configured for V/Stol and supersonic flight at altitude. An analysis of the operating conditions for a typical application was made. Several methods of supporting combustion under these conditions and in the space available were considered. Experimental research was carried out on eighteen combustion chamber liners of the can type, sixteen of which were of experimental design for this program. Correlations were made among various performance parameters and between design factors and performance. A design which promises to meet requirements was developed. The work is continuing into a second year, as Phase II.

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Security Classification